MIT Technology Review

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R@GE

Free speech in the era of its technological amplification

By Jason Pontin, p60


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From the Editor

When did disruption become the overwhelming fact of business? It wasn't always so. But the most admired businesses of the last 30 years have been technology companies or industrial companies that invested heavily in research and development, whose comparative advantage was their capacity to commercialize disruptive innovations or resist the innovations of other entities.

The common perception that disruptive innovations are occurring more frequently is based on something real. From 1955 to 1993 the median turnover of the *Fortune* 500 was 29 companies per year, according to a 2012 Kaufman Foundation report. From 1995 to 2011 the turnover has been 39 companies a year. (The report argues that increased disruption can't be the only explanation: the higher turnover also reflects the changing methodology of *Fortune*'s list, which after 1994 included more volatile nonindustrial firms, and also more mergers and acquisitions.) A turnover of 39 companies a year means that more than half the companies in the *Fortune* 500 are replaced every decade, if one includes companies coming on and off the list.

But the preoccupation with disruptive innovations is not only statistical. It is the product of our wonder at the rapid changes forced by technology companies over the last 30 years, and of our understanding of why other companies are unable to innovate. That understanding derives from the research of Clayton Christensen, a professor at Harvard Business School, whose first book, *The Innovator's Dilemma* (1997), introduced the phrase "disruptive innovation." Christensen meant the phrase to suggest an innovation that created a new market and disrupted an existing marketplace, and he provided a grim explanation of why *Fortune* 500 companies, no matter how efficiently managed, fell off the list: for impeccably rational reasons, their managers were busy satisfying the existing demands of customers instead of imagining how they might satisfy future needs. By definition, satisfying future needs with an entirely new product or service often meant destroying an existing business with its associated revenues, trained employees, production facilities, and supply chains. Creative destruction, Christensen taught, was always easier for a startup with nothing to lose than for an established firm.

We don't believe that disruptive innovation occurs only in small companies (and, in fairness, Christensen described how established firms might become innovative in a 2003 sequel, *The Innovator's Solution*). This annual issue of *MIT Technology Review*, dedicated to listing the 50 most disruptive companies in the world, celebrates two sorts of disruptive innovators. The first are the startups whose breakthroughs will overthrow the market dominance of larger companies: they include the thermostat maker Nest, profiled on page 28, and Ambri, a maker of grid-scale batteries, whose technology is described on page 48. The second sort of disruptive innovators are established firms willing to deconstruct their own businesses, because they recognize Christensen's grim logic. These companies include Microsoft, whose transformative Windows 8 operating system is reviewed on page 76, and Xerox, whose chief executive, Ursula Burns, is interviewed on page 38.

Remaining one of our 50 Disruptive Companies is even less sure a thing than remaining a *Fortune* 500 company. Brian Bergstein, *MIT Technology Review*'s deputy editor, notes in the introduction to the package on page 26, "The pace of technological change is brutal … Only 15 of these 50 companies were also here last year." But write to me at jason.pontin@technologyreview.com and tell me what you think.

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NATIONAL INSTRUMENTS

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84 YEARS AGO

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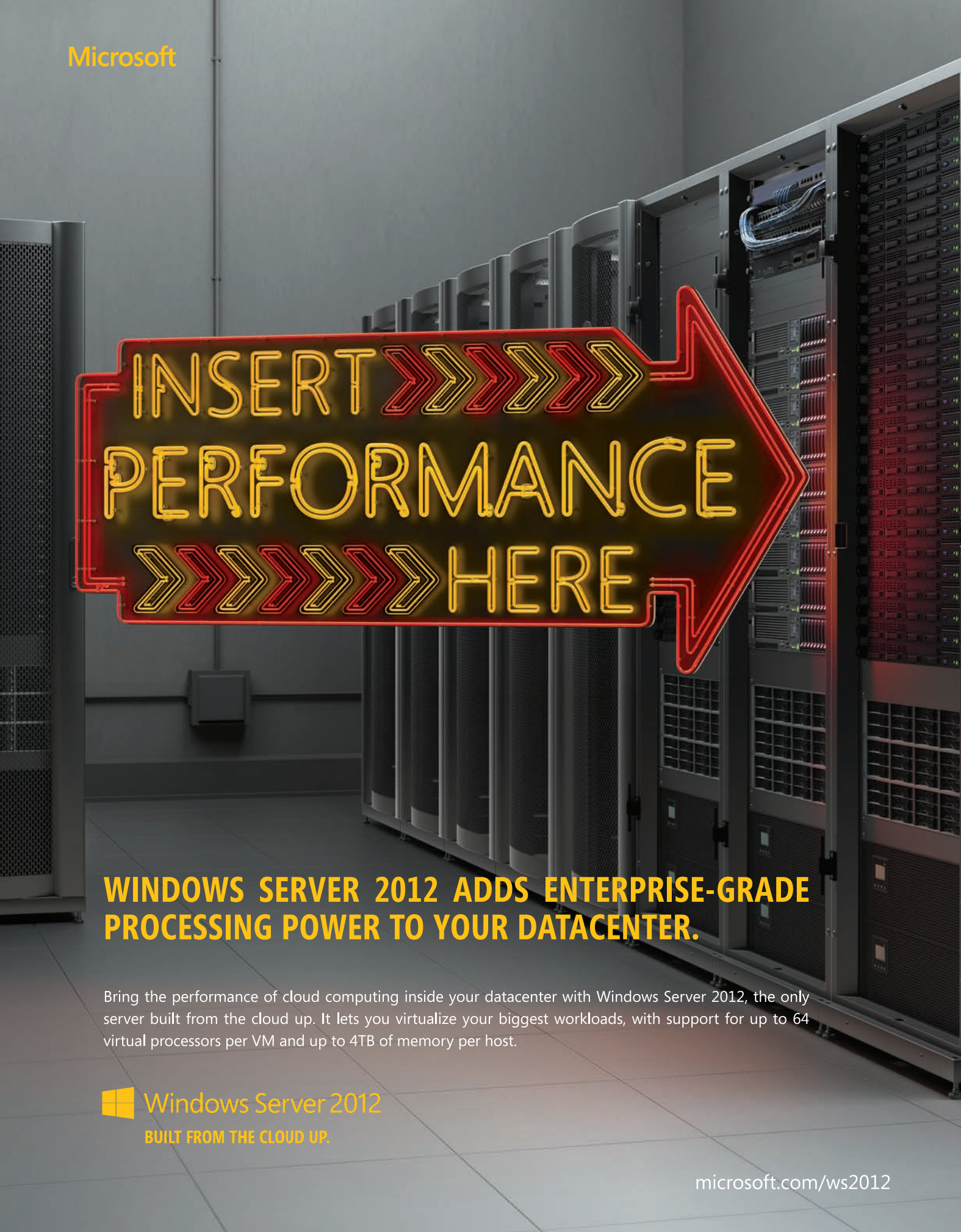
Free Speech, p60

GABRIELA HASBUN



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Meeting Global Challenges: Discovery and Innovation

Scientific discovery and innovation are helping to drive solutions to current and future global challenges. Economic progress in every community worldwide has meanwhile become increasingly interdependent with advances in science and technology. Challenges related to ensuring sufficient food for a growing population, quality healthcare, renewable fuels, and a sustainable and enriching environment demand innovation and international dialogue. Addressing these challenges depends upon discoveries emerging from the convergence of physical, life, engineering, and social sciences in innovative ways that are most useful to society.

In a weakened global economy, many countries have begun to limit their investments in the future. Yet, investments in innovations – including funding for education as well as basic and applied research – represent our best prospect for a sustainable environment and increased economic growth. Economists estimate, after all, that innovation in science and technology are the source of more than half of the economic growth in many countries. By increasing innovation in sustainable products and processes, world economies can continue to enhance human welfare across society.

Innovation springs from the translation, production, and distribution of discovery and invention to society. In the contemporary world, this is not a linear process, but rather, a matrix of interactions. Societies, with support from public and private sectors and institutions, struggle to integrate the necessary disciplines and interests into this matrix. Within the scientific and engineering community, we need to better integrate different disciplines and voices into a consensus supporting innovation. Developed and developing countries that accomplish this will become the economies of the future.

At the same time, it is imperative that we work in ways that are transparent and open to a diversity of contributors and ideas. Assessing risk versus benefit in adopting an innovation is complex and depends upon an open dialogue. Only then will we realize the promise of furthering scientific discovery and innovation to meet pressing global challenges and improve quality of life.

Call for Poster Submissions

Online entries will be accepted at **www.aaas.org/meetings** beginning **14 May 2013.**

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Feedback

5 Most Discussed Stories

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Dear Mr. President

There are many serious problems facing human civilization. Man-made climate change is hardly the only one. Running out of affordable energy is at least as important.
Wallace Manheimer
Camden, Maine

While Republicans rant about leaving the debt crisis to our children—a crisis they largely created—it pales in comparison to the risk of leaving them an environment in which life on Earth as we know it becomes impossible.
– zbmitt

A Business Report on Digital Education

At age 80, I watch my granddaughters take online courses thinking this was always the way. I have been deeply concerned about the way for-profit colleges charge ever more each year. There are few things in life where I can sit back and say "Yeah! The world isn't coming apart at the seams." But this concept of online courses is an idea whose time has come—congratulations to all involved.
– larrykueneman

Q+A: Bono

I never thought I'd see the day that someone like Bono would appear on cover of *MIT Technology Review*. If readers needed any proof that you've lost your way as a once-must-read publication, this is it.
– mrscissors

Let's step back for a moment and look at the article for what it is about, regardless of whose face is on the cover. Bono discusses the impact that technology has and will have on Africa. You can't deny the advantages that technology has had on farming not only in Africa but across the globe.
– wtf!

The Difference Between Makers and Manufacturers

Someone donated a computer to Bill Gates's school. What happens when someone donates a 3-D printer to a junior high? We could see a new generation of geek product designers marketing their designs to large manufacturers. **– OldTech**

In a very few years, 3-D printers will be multimaterial devices driven by more powerful and easier-to-use design software. How do I know that? Because that's the path that we've followed for 40 years. **– david.smith**

A More Perfect Union

What this article makes plain is that big data is a game changer. If you want to get elected, you need to be able to leverage this information. To both access it and use it is prohibitively expensive to the vast majority of Americans. He who controls access to this information controls the election. It further raises the barriers that block entry into politics.
– blindwanderer

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Missed Opportunity

In your essay "Dear Mr. President" (January/February 2013), you could have made an important contribution to the discussion of climate change. Instead, there was a lot of ballyhoo about more research on politically correct but amorphous green technologies but not a word on the one solution that is within our grasp: new, safe nuclear reactor designs. New designs can be made much safer than older ones, to the point that the chance of Fukushima-like accidents becomes less than the chance of being struck by an asteroid, and there is enough readily available fuel to power the entire world for generations to come. And no carbon emissions.

Thomas F. Hafer
Arlington, Virginia

The Real Value Revealed

Your biomedicine editor Susan Young was spot on to notice the value of using the genome for dosage and personalization of blood-thinner drugs ("Why We Have a Right to Consumer Genetics," January/February 2013). That's exactly where the advantage of this sort of diagnostic lies: not in the prediction or prevention of disease, but in the personalization of treatment after you already have the symptoms. Unfortunately, instead of being adopted by clinics, 23andMe is confined by regulation, and thus is stuck with the "personal entertainment" angle.

– bzdyelnik

Let's Get Small

Your comment regarding "the smallness of our concerns and the dishonesty of our arguments" (From the Editor, January/February 2013) was perfect. Although party politics took hold immediately after the first election of Washington, for the next 150 years most of the men who ran for the highest office (and other offices) could be called statesmen and were very concerned with the important issues of their day. Good editorial.

David Champeau
Cranford, New Jersey

"Not a word on the one solution that is within our grasp: new, safe nuclear reactor designs."

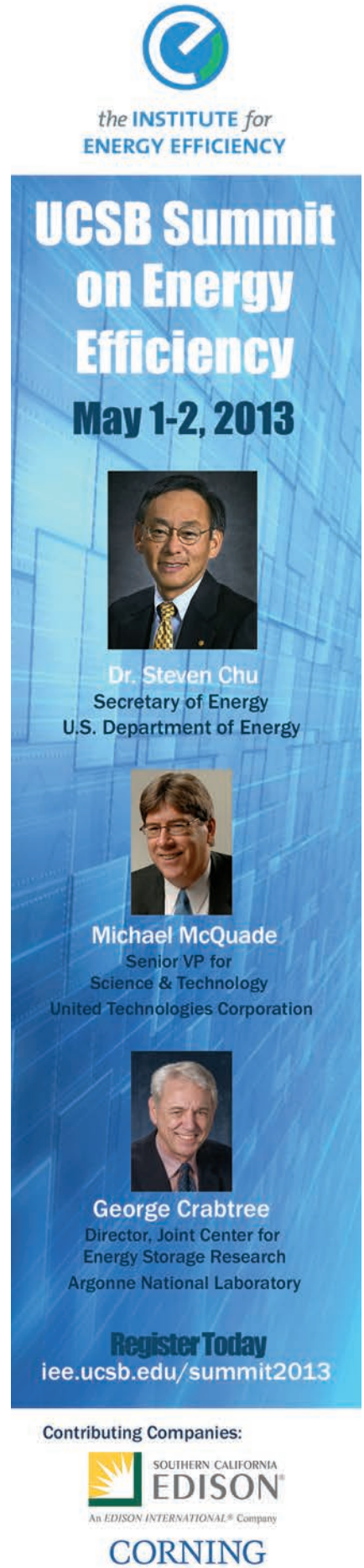
Frack Attack

In "Safer Fracking" (Views, January/February 2013), Mark Brownstein of the Environmental Defense Fund writes that "the burden of proof is on industry and regulators to show that shale gas development can be done without polluting the water and air or damaging our climate." I disagree. The burden of proof is on protesters to demonstrate that there is actual or potential damage in the real rather than hypothetical world.

What most people don't realize is that fracking has been used for over 60 years on vertical wells (I recall as a child seeing it done in the late 1940s). It seems that over a million wells have been hydraulically fractured throughout the world without a single proven case of water pollution. That's only logical, since the fracturing usually takes places a mile or more through many impervious layers of rock, below typical domestic water sources that are a few or a hundred feet below the ground.

Given the large and very long record of safe hydraulic fracturing per se, it seems to me that scaremongers such as Mark Brownstein should document what the real and specific risks are before advocating misdirected or ineffective regulations.

Phillip Hawley
La Jolla, California



Views

Jim Barton

Jane Long

Alan MacCormack

ENTERTAINMENT

Screen Break

The TV industry must adapt because viewers now see television as just one screen among many, says Jim Barton.

The video consumption experience provided by traditional distributors—TV companies—has never been further from the one consumers would prefer. The increasing prevalence of mobile devices with access to video has only widened the gulf, to the point that those old distribution models are confronting a serious challenge (see our feature on Apple TV, page 40).

Rapid adoption of mobile Internet-connected devices is changing the way consumers think about and experience video. Touch screens offer a natural control surface. Browsing large collections of video content is easy, and controlling the viewing experience is simple and straightforward. Consumers want their videos to be available to them at all times, wherever they may be, on whatever device they have with them. People are also now accustomed to being surrounded by multiple screens as a natural part of life. We are all familiar with the scene of a family watching television from the couch, each viewer with a mobile device in hand.

All this makes traditional television viewing feel unwieldy. The remote control and the television-presented user interface can't compare in ease and simplicity with control through a handheld touch screen. Well reviewed though the on-screen TiVo interface has been, for example, it's not nearly as easy to use as the TiVo iPad application. Worse, cable, telecom, and satellite television distributors use their dominance to enforce old-style television viewing, requiring the use of proprietary set-top boxes to access programming and constraining alternative suppliers such as TiVo or Netflix. Newer products such as "smart TVs," Apple TV, and Google TV try to translate the mobile or desktop computer experience to the TV screen, but it works poorly.

What people really want is control over their viewing experience, total mobility, and true on-demand viewing for all types of content. The current aggregators and distributors of video content seem to want just the opposite—an experience focused on the television, with a confusing array of windows and tiers for viewing, controlled by the provider. This model from the past, with its high overhead for the consumer, is increasingly difficult to defend in an interconnected, mobile world. The television is a great way to play back video, but it is a poor and cumbersome delivery vehicle for anything more. In the end, it is just one more screen.

Jim Barton, a cofounder of TiVo, is currently working on a new video entertainment startup company.

ENVIRONMENT

Carbon Cleanup

Acting to solve our climate problem will take big investment and a strategic approach, says Jane Long.

Climate change seems to be back on the political agenda: a majority of the U.S. public favors action, and President Obama has promised new efforts. The hard part is deciding what to do.

Previous attempts to deal with global warming have focused on marginally reducing greenhouse-gas emissions, but that doesn't come close to solving the problem. The carbon dioxide we put into the atmosphere stays there effectively forever, so the problem will just get bigger

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Views

until we stop all emissions. Our strategy should aim to eliminate them and deal with the harm we have already caused. Here's an outline of how we could do it.

Reaching zero emissions while meeting our energy needs will require us to reduce demand. Our first step should be to commit to never building another energy-inefficient city, building, vehicle, or industry.

Next we should focus on energy production, resolving to produce only zero-emission electricity and to electrify heat and transportation. Renewable electricity is popular, but we have to overbuild by a factor of three or four to make up for times the sun doesn't shine and the wind doesn't blow. Alongside that extensive new infrastructure, large-scale energy storage and some ability to control demand to fit supply will be needed, and that could take many decades. Plentiful, cheap natural gas creates half the emissions of coal, but making that fuel part of a zero-emission world will require some means of carbon capture and storage (CCS). Nuclear power works 95 percent of the time at large scale without emissions, and new passively safe designs are available. We can create a reliable emission-free electricity system for both rich and poor nations by combining CCS, nuclear power, and renewables.

Not all transport can be electrified, and it is unlikely that biofuels can be made at scale without affecting food availability or generating greenhouse gases, so we must also search for alternative scalable, non-biomass-based zero-carbon fuels.

No matter how fast we act, the effects of climate change could become severe. Could we remove carbon dioxide from the atmosphere, or shade the planet with sulfate particles? (See "A Cheap and Easy Plan to Stop Global Warming," page 52.) Most such geoengineering concepts will probably turn out to be bad ideas, and caution is appropriate. But we may need to take steps like these in the future. We should begin systematic geoengineering research now.

Nuclear power, CCS, electrification, energy storage, decarbonized fuel, efficiency standards, and geoengineering: our to-do list is long. But we have no choice.

Jane Long chairs the California's Energy Future committee at the California Council on Science and Technology and cochairs the Bipartisan Policy Center's geoengineering task force.

INNOVATION

Embracing Uncertainty

Giants like Microsoft face the same challenges that doomed companies like Polaroid, says Alan MacCormack.

It's an age-old question. Why do successful technology companies stumble once they reach the top? Legendary businesses such as Digital Equipment Corporation, Polaroid, and Atari all led their industries yet eventually succumbed to the kinds of technological innovation they had pioneered. The pace of such change is quickening. In 2008, RIM's BlackBerry conquered the mobile-phone industry, and the company's value hit $80 billion. Less than five years later its devices have become passé, and its stock has tumbled 90 percent. Today Microsoft, Nokia, and even Apple must be wary of similar fates.

Staying ahead means welcoming uncertainty.

Alan MacCormack

Developing breakthroughs involves creating something new and valuable (see "50 Disruptive Companies 2013," page 26). It is inherently uncertain. And therein lies the challenge. As organizations become successful and grow, uncertainty is the enemy. They seek to eliminate variation and increase efficiency. They identify best practices and design standard operating procedures. This can make a business wildly efficient at what it does today. But it has a serious downside: an avoidance of novelty that can eat at the very soul of a company.

To overcome this challenge, companies must relearn skills and capabilities that brought them industry leadership—adopting processes that create variation, not eliminate it, and valuing flexibility over the relentless pursuit of efficiency.

First, they must design diversity into their DNA, to combat the natural forces that act to reduce it. For example, Google allows some engineers to spend 20 percent of their time on side projects and gives added resources to those ideas with the most merit. Intel funds hundreds of university grants to learn about new technologies outside its "silicon road map." Netflix tapped the creative juices of hundreds of external developers, offering a $1 million prize for the algorithm that could best predict consumers' movie preferences.

Second, organizations must embrace change, not resist it. They must explore, without expecting the initial specification to represent more than a starting point. Their processes must reflect the fact that your first plan is always wrong—meaning the challenge is to quickly and cheaply work out how it can be improved. They must understand that trial and error allows rapid discovery of what cannot be uncovered through even the most brilliant analysis and planning.

Ultimately, staying ahead in a digital age requires companies to welcome the uncertainty that endangers their current business. Only by doing this can they discover the new possibilities that lie ahead.

Alan MacCormack is an adjunct professor at Harvard Business School who focuses on innovation in high-technology industries.

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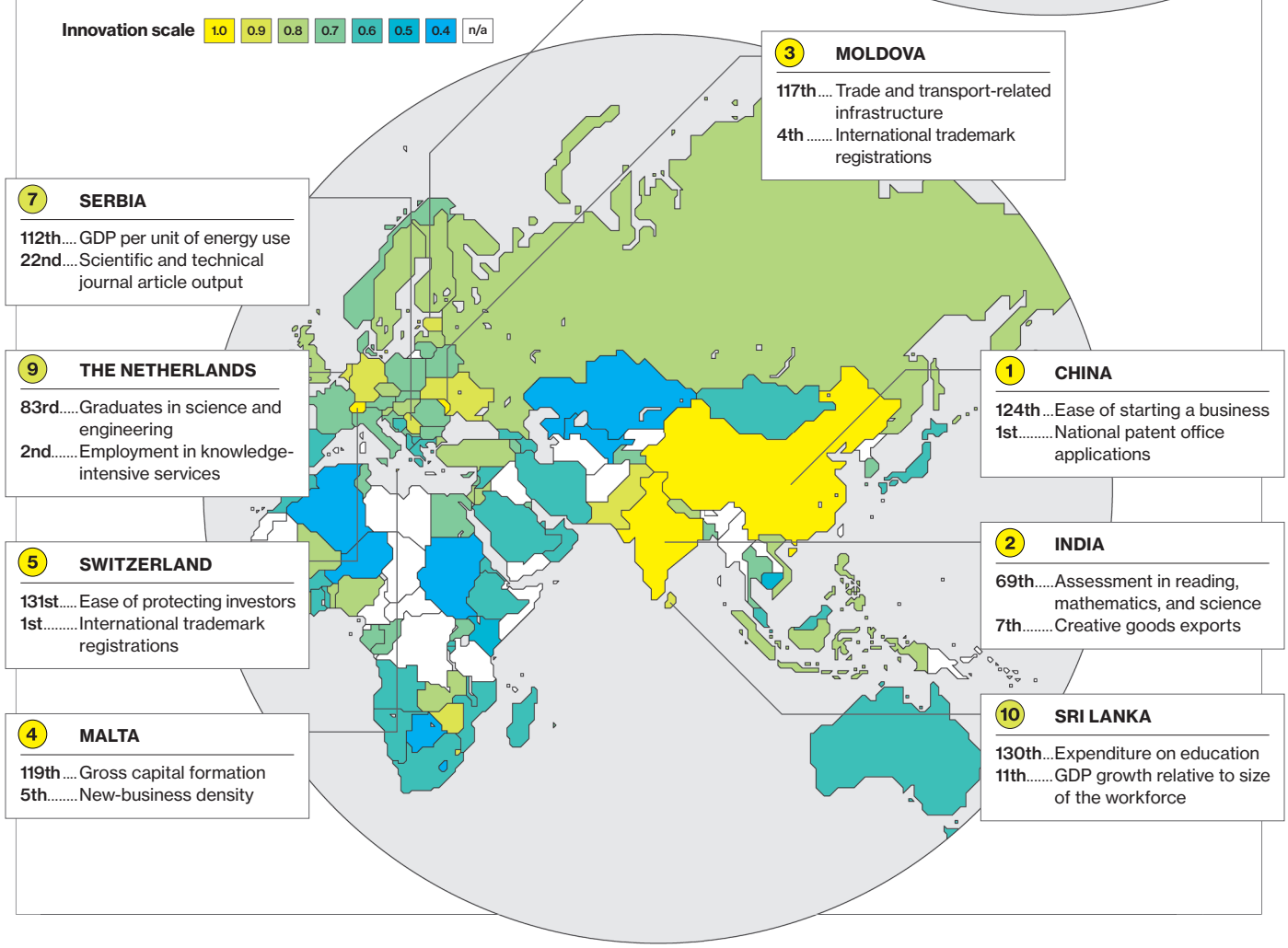
Upfront

The innovation efficiency index

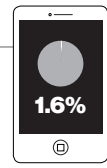
For the past five years, the Global Innovation Index has ranked countries' ability to stimulate invention. Published by the French business school INSEAD and the World Intellectual Property Organization, it compares 141 nations on more than 80 metrics, which are adjusted for population or GDP. Unsurprisingly, the top-performing countries are wealthy. But the report also analyzes which countries are best at making scientific advances or creating intellectual property despite disadvantages like unsophisticated markets and infrastructure. This "innovation efficiency" index makes a different group of countries stand out, as shown in the maps below and to the right. *—Mike Orcutt*

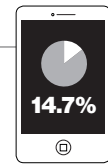


GRAPHIC BY CARL DE TORRES; DATA FROM INSEAD AND THE WORLD INTELLECTUAL PROPERTY ORGANIZATION

Upfront

Worldwide Internet usage occurring on mobile devices (excluding tablets) in January 2010





The same figure in January 2013

Your Gadgets Are Slowly Breaking the Internet

The Internet isn't ready for the ongoing explosion of connected devices. Now research labs around the country are scrambling for solutions.

By David Talbot

Behind all the dazzling mobile devices on the market is a looming problem: how to make the networks that support them function securely and efficiently.

With little fanfare, potential solutions are taking shape in several academic labs. The grand challenge is to overhaul the Internet to better serve an expected flood of 15 billion network-connected devices—many of them mobile—by 2015, according to estimates by Intel. That's up from five billion today.

The Internet was designed to dispatch data to fixed addresses of static computers connected to a single network. But today it connects a riot of diverse gadgets that can zip from place to place and connect to many different networks.

As the underlying networks have been reworked to make way for new technologies, serious inefficiencies and security problems have arisen. Networks are needlessly congested, reducing bandwidth below advertised levels (see "Three Questions for Tom Leighton," page 22). And it can be difficult to reliably authenticate who actually sent something, and that the thing is what it purports to be (a bank login page, for instance). It's not as though everything will crash "when you add one more device," says Peter Steenkiste, a computer scientist at Carnegie Mellon University. "But I do have a sense this is a creeping problem of complexity."

Fundamentally new network designs have taken shape and are being tested at universities under the National Science Foundation's Future Internet Architecture Program, launched in 2010. One key idea is that users should consistently be able to obtain data from the nearest location rather than some specific data center at a fixed address.

"Today I have on my desk a smartphone, a tablet, and a Mac computer. To move data between them, the request goes all the way to the cloud—God knows where that is—so it can come back here to another device that is two feet away," says Lixia Zhang, a computer scientist at the University of California, Los Angeles. "That is wrong. It is simply wrong."

Things would work quite differently under the Named Data Networking (NDN) project that Zhang heads. Under

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Upfront

QUOTED

"I can't imagine a computer without touch anymore. Once you've experienced it, it's really hard to go back."

—Julie Larson-Green, the new head of Windows development at Microsoft.

NDN, users request pieces of data by their names instead of the IP address where they can be found. Using data names could, among other things, allow easy sharing of data directly between devices.

"I think we can improve the speed, throughput, and overall efficiency," says Zhang. "Today you have many data centers that can have thousands of people asking for the same piece of data. An NDN network just finds the nearest copy of that data. Conceptually this is pretty simple, but it is really a revolution."

Eventually, devices could attach to two networks at the same time and combine data from each.

This data-centric concept allows the data itself to be directly secured, rather than relying on measures such as VPNs and firewalls. In an NDN network, every named piece of data is associated with a cryptographic key, and every data packet carries a cryptographic signature that assures the data's provenance; if privacy is needed, the data is encrypted as well.

In addition to Zhang's project, the National Science Foundation funds Internet architecture projects with similar goals at Rutgers, the University of Pennsylvania, and Carnegie Mellon, where Steenkiste runs the expressive Internet architecture, or XIA, project. Like NDN, that project is exploring ways that data could be named and transferred between users. The overall goal of XIA is to make networks more flexible so that they can adapt to future technologies.

The Rutgers project is called Mobility First and is trying to make mobile devices and car networks a more seamless part of the infrastructure. One way it might do this is by creating routing systems that are more tolerant of the delays that occur when devices are temporarily offline. The Rutgers group is also exploring ways that communication networks could let users better control who sees their location and personal information.

The fourth project, at Penn, assumes a future in which people store their data and do their computation in remote data centers in the "cloud." Dubbed Nebula, the effort emphasizes the need for extremely fast and highly secure networks.

Several early demonstrations of these Internet architecture projects have taken place over the past year, and more are expected in the coming months. Dipankar Raychaudhuri, head of the Rutgers Winlab, says it should be possible to compare their effectiveness within two years.

It's too early to say which, if any, of these alternative approaches will win out, says David Clark, an MIT computer scientist and the Internet's former chief protocol architect. "All are research, all are speculative, and are potentially exciting," he says.

But the NDN effort "is the most revolutionary," he adds. "The project really changes the underlying model of what a network does. It replaces communication among endpoints with access to data, wherever it may be."

Among other things, new architectures could allow devices to attach to two or more networks at the same time. Today your smartphone can switch back and forth between, say, 4G and Wi-Fi, but it can't use them both and combine the data coming from each. The root of the problem is that the original protocols assumed only a single network interface. With the new system. Raychaudhuri says, "you could, in principle, remain connected to both networks, and the network could decide how to send you the data at each moment."

TO MARKET

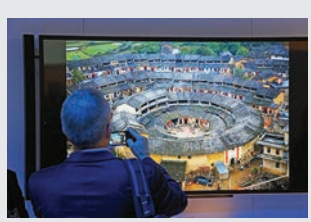
More-Colorful TVs

Triluminos Display

COMPANIES:
Sony, QD Vision

PRICE:
Not yet disclosed

AVAILABILITY:
Spring



Sony is using nanoscale particles called quantum dots to improve the color of three models of high-end televisions. This marks the first time that quantum dots have been used in a mass-produced consumer electronics product. Quantum dots have fascinated researchers because of their unusual properties: they emit very specific wavelengths of light, and their precise colors can be tuned by changing their size. By putting quantum dots into an LCD TV's backlights (the lights that illuminate the pixels), Sony can increase the range of available colors by about 50 percent. Sony is incorporating technology from QD Vision, which has been working to commercialize advances made at MIT over a decade ago.

COURTESY OF MICROSOFT; TOM SIMONITE/MIT TECHNOLOGY REVIEW

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Upfront

QUOTED

"Buying something on the Web is a fairly awful experience that we've just gotten used to."

—Manu Sporny, founder of Digital Bazaar, a startup that is proposing an open standard for inexpensive online money transfers within Web browsers.

Will France Give Up Its Role as a Nuclear Powerhouse?

The country gets most of its electricity from nuclear power. But now it's debating whether to wean itself from it.

By Peter Fairley

A council appointed by French president François Hollande is kicking off a nationwide debate that could shift France away from nuclear and toward renewable energy. It is a dramatic development in light of France's outsize nuclear investments: the country produces more nuclear energy than any other country besides the United States, and it relies on reactors for more than three-quarters of its power generation, a higher percentage than any other country.

Nothing will change quickly; given its heavy reliance on nuclear power, the country cannot rapidly phase out its reactors the way Germany plans to. And France has already lost its leadership role to global competitors. "The new leaders in nuclear expansion globally are the Chinese and Koreans," says Andrew Kadak, a nuclear science and engineering research scientist at MIT. Experts such as Kadak predict, however, that over the long haul a future France that abandons nuclear would impoverish global nuclear R&D.

During his election campaign last year, Hollande called for reducing nuclear to half of France's power supply by 2025. If that comes to pass, the new reactor in Normandy that the state-owned utility Electricité de France (EDF) expects to fire up in 2016 could be the country's last.

Worldwide nuclear R&D could be diminished if France abandons the technology.

"France's reduced backing for nuclear will certainly be a blow to nuclear power's reputation," says Chi-Jen Yang, an expert in technology policy at Duke University's Center on Global Change. However, the big loser could be France itself, which would probably have less ability to export its own technology: the third-generation European Pressurized Reactor design developed by the French nuclear technology firm Areva. That is the same design that EDF is using. Areva is also building a nuclear plant with the new design in Finland and bidding globally to build more, including a second unit for Finland. EDF is building two such plants in China and has proposed deploying the technology in the United States and the United Kingdom, among other countries.

But even though France's role in the reactor market is already slipping, it remains a major player in the development of advanced nuclear technologies that will be relevant for decades. The Commissariat à l'énergie atomique—France's counterpart to the U.S. Department of Energy—has been spending about 1.5 billion euros ($2 billion) annually on R&D for "nuclear technologies of the future." That dwarfs the $885 million that Congress provided for the DOE's nuclear energy R&D in 2011.

TO MARKET

iPhone Oxygen Scan

iSpO2

COMPANY: Masimo

PRICE: $249

AVAILABILITY: Now

This pulse oximeter that connects to an iPhone or iPad can precisely detect blood oxygen levels, which is vital information for pilots who fly unpressurized aircraft and hikers who climb to high elevations. When the user puts a finger into the oximeter, it shines both infrared and red light into the digit; blood absorbs different amounts of each frequency depending on how much oxygen is carried by red blood cells. An associated app on the iPad or iPhone displays a readout. Blood-oxygen levels can also be useful information in everyday workouts. However, for now at least, this finger sensor and its connector cord are probably too cumbersome to be used anywhere at the gym but on the treadmill.

DAVID I. LEHN

$6.21

The cost, per watt of electricity, of an average solar panel installation in the United States

$3.42

The comparable cost in Germany, where solar installers face fewer bureaucratic hurdles

That investment has led to expertise that could be lost if France pulls back from nuclear energy broadly. Kadak cites the French capacity to reprocess spent nuclear fuel. The world may ultimately need that technology to manage nuclear waste. "This is an area where the French are clearly leaders," he says. If the French retrench, reprocessing development "[will] suffer globally and will affect our ability to recycle nuclear fuel."

Burton Richter, a Nobel Prize–winning physicist at Stanford University and former board member for Areva's U.S. subsidiary, says France's energy agency has been "more effective than the U.S. labs" in developing so-called Generation IV reactors. These advanced reactors can "breed" their own fuel by irradiating and transmuting unenriched uranium. Other designs can break down spent nuclear fuel.

France's energy debate is scheduled to wrap up in July, and the government is expected to propose legislation in October. Antinuclear activists say public opinion is with them, citing a poll commissioned by Greenpeace last year in which 80 percent endorsed the statement "France is too dependent on nuclear energy."

Nuclear proponents retort that the debate could recommit France to nuclear energy, citing growing worries over jobs. Meanwhile, French automakers are embracing electric vehicles, which will be hard to charge with low-carbon energy if France cuts back on nuclear reactors.

As a result, nuclear and renewables could coexist in France, notes Charles Forsberg, executive director of the MIT Nuclear Fuel Cycle Project. "The French establishment is looking at whether they can electrify transportation and the rest of industry, which would imply a massive increase in electricity demand," he says. "At the end of the day, the French will likely have slow nuclear and accelerated renewables growth."

DATA FROM LAWRENCE LIVERMORE NATIONAL LABORATORY; PEBBLE; ASSOCIATED PRESS/MARY ALTAFFER

Pebble: A Transitional Form of Wearable Computer

The e-ink wristwatch is useful precisely because it doesn't try to be a full computer–just a screen.

By John Pavlus

Founder Eric Migicovsky shows off his Pebble watch.

I used to wonder who would solve the "jetpack problem" for wearable computers like the upcoming Google Glass eyewear: who will present a use case for them that doesn't presume sci-fi coolness for its own sake? Pebble, the e-ink wristwatch that was funded by admirers on Kickstarter and unveiled this winter, is as close to an answer as I've seen.

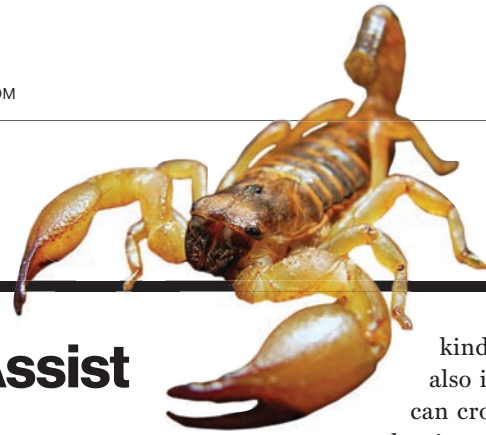
That's because Pebble cleverly makes use of the computers many of us already "wear": smartphones, which spend most of their useful lives concealed in our pockets. The problem that Pebble seeks to solve isn't "How can I cram all that functionality into something I strap to my arm or face?" Instead, it asks, "How can I create an auxiliary display for that device that doesn't require me to lug it out of my pocket for simple interactions?"

In other words, Pebble seeks to solve a practical interface problem by being only that—an interface. A very simplified one, too. Not a do-everything computer or portal into augmented reality, like Google Glass. And not an expensive bauble that's good for only one thing, like Fuelband or Fitbit. Pebble is just a more convenient screen for your smartphone.

Most of your smartphone's functions would be cumbersome and annoying to use if the whole thing lived on your wrist, Dick Tracy style. At the same time, a lot of the simpler functions that our smartphones have taken over—like acting as timepieces, or displaying the weather, or nudging us when an important e-mail arrives—don't really require interacting with the entire device. When you feel your phone buzzing in your pocket, you have to pull the whole thing out just to find out what the notification is for. Glancing at a discreet wrist display is much less cumbersome and annoying.

This kind of ultra-simple, "glanceable" interaction is where the near future of "wearables" probably lies. A tiny screen hovering in front of your eyeball is certainly glanceable, but it's also not really *un*-glanceable. Whereas a cheap e-ink screen that's smart enough to connect to the brick in your pocket is just "there" enough to make sense when you need it and not bother you when you don't.

Upfront



Scorpion Venom Could Assist Cancer Surgeons

A compound derived from a toxin in the venom could help doctors differentiate between healthy and cancerous tissue.

By Susan Young

Several years ago, Jim Olson, a pediatric neuro-oncologist at Seattle Children's Hospital, was reviewing with his colleagues the case of a 17-year-old girl who had undergone brain surgery to remove a tumor. An MRI scan revealed a thumb-size piece of tumor that the surgeons had left behind. In the operating room, the tumor tissue had looked just like healthy brain tissue. During the review meeting, the chief of neurosurgery turned to Olson and said: "Jim, you have to come up with a way to light these cells up." So Olson and a neurosurgical resident started searching for a way to highlight cancer cells in the operating room.

Eventually, they came across a report of a scorpion toxin that binds to brain tumors but not healthy cells. By linking a synthetic version of this protein to a molecule that glows in near-infrared light, the researchers think they may have found what they call "tumor paint."

In their very first test, Olson and his colleague injected the compound into the tail vein of a mouse whose body harbored a transplanted human tumor. "Within 15 to 20 minutes, the tumor started to glow, bright and distinct from the rest of the mouse," says Olson. The technology has been licensed by Blaze Bioscience, a Seattle company that Olson cofounded. He says human trials will begin late this year.

The scorpion toxin works because it binds to a protein produced by certain kinds of tumor cells. It also is special because it can cross the blood-brain barrier—a cellular and molecular fortification that lines blood vessels in the brain and prevents most compounds from entering. Usually, peptides such as the venom "don't get into the brain unless they bind to something specific that carries it in there," says Harald Sontheimer, a neurobiologist at the University of Alabama in Birmingham, who first identified the neurological potential of the scorpion protein.

The tumor paint developed by Olson may also light up cancer outside the brain; animal studies suggest it could demarcate tumors in the prostate, colon, breast, and elsewhere.

Despite its venomous origins, the compound seems to be safe. A biotech company started by Sontheimer showed in early clinical trials that a version of the scorpion toxin tagged with radioactive iodine didn't harm patients. However, the company closed before late-stage testing began.

THREE QUESTIONS

Tom Leighton

The Akamai Technologies CEO wants to apply the company's Web-optimization expertise to mobile networks.

How well do mobile networks deliver Internet content?
The performance of mobile devices, especially on cellular networks, can be very poor. If you look at download speeds from top commercial sites, they're equivalent to landline speeds nine years ago—that's like the Dark Ages of the Internet. Users expect it to be like TV: change a channel and it just changes. They think the Web is supposed to work that way.

How can Akamai's new site-performance service, Aqua Ion, speed this up?
We can reduce the amount of bandwidth you need to get served. With Aqua Ion, when you go to a website, you actually go to an Akamai server. We detect what device you are using and how well it's connected. We will compress the picture or other object [accordingly]. That relieves the network and provides a better experience for the user.

Can our devices shoulder more of the burden?
We call it client-assisted delivery. If you have a well-connected, well-powered machine, [it] can be used to send information to a neighbor. Then we don't have to send information to each neighbor individually. Thirty million devices, typically laptops or desktops, are doing this. But there are billions of devices out there. We want to be on every device. —*David Talbot*

MATT REINBOLD; DAVID TALBOT/MIT TECHNOLOGY REVIEW

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Upfront

QUOTED

"There's no more important project than understanding intelligence and re-creating it."

—Ray Kurzweil, speaking about the language-recognition technologies he hopes to develop in his new role as Google's director of engineering.

Nanostructures Boost Battery Life Fivefold

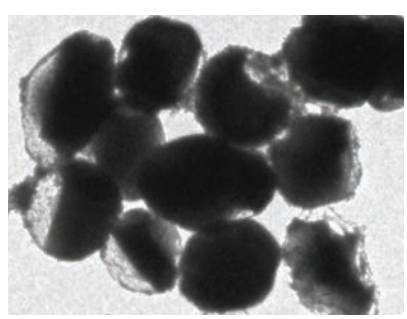
The materials could make batteries that store far more energy than lithium-ion ones.

By Kevin Bullis

Some of the most promising battery chemistries could store several times more energy than today's lithium-ion batteries and cost much less. But these alternatives have had a fatal flaw. They can't be recharged many times before they stop working, making them useless for applications such as electric cars. Now Stanford researchers have created novel nanostructures that greatly increase the number of times batteries with one of these chemistries can be recharged, even to levels high enough for many commercial applications.

Whereas previous research reports have celebrated the ability to recharge a lithium-sulfur battery 150 times, the Stanford researchers recharged their battery 1,000 times and still retained 67 percent of its energy storage capacity. In some electric vehicles, that would be enough to last several years. Yi Cui, a professor of materials science and engineering at Stanford, says the nanomaterials can be made with simple methods that lend themselves to high-volume manufacturing.

The nanostructures address two problems with previous lithium-sulfur batteries. When the batteries are discharged, sulfur combines with lithium to form lithium sulfide, and when they're charged, sulfur forms again. But the reaction isn't direct; intermediate compounds called polysulfides are formed. If these polysulfides migrate out of an electrode, the reactions aren't completed, which limits the amount of energy the battery can store. Over several recharging cycles, these intermediate products accumulate, reducing battery capacity more.



A transmission electron micrograph of nanostructures made of titanium oxide (light material) and sulfur (dark material).

Several researchers have demonstrated that various nanostructures can help trap the polysulfides within an electrode, but these designs run up against a second problem with lithium-sulfur batteries. The sulfur swells and can damage the nanostructures, allowing the polysulfides to escape.

The Stanford researchers made spherical nanoparticles of sulfur and coated them with a titanium-oxide shell that traps the polysulfides and keeps them from migrating out of an electrode. They then dissolved part of the sulfur, creating space inside the shell for the remaining sulfur to expand.

Much more work remains, however. Electric car batteries would ideally retain 80 percent of their capacity for as many as 3,000 charging cycles.

TO MARKET

Tabletop Gaming PC

Idea Centre Horizon

COMPANY: Lenovo

PRICE: $1,700 and up

AVAILABILITY: Summer

When it is upright, this is basi-cally just a big (27 inches on the diagonal) touch-screen computer that runs Windows and handles everyday PC tasks. But when you lay it flat on a table, a specially designed interface called Aura takes over to make it easy for multiple people to play electronic versions of board games like Monopoly and tabletop games like air hockey. The computer comes with dice and joysticks and other controllers that can be used to manipulate the on-screen action. The manufacturer, Lenovo, says it is also exploring whether to produce a 39-inch version of the computer.

HELENE DELILLO; NATURE COMMUNICATIONS, COURTESY OF LENOVO

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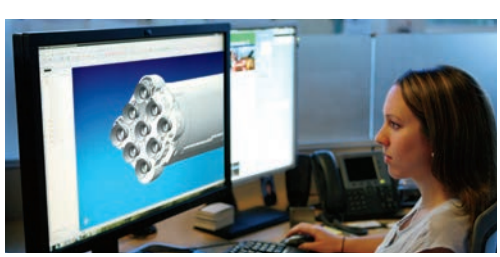

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50 DISRUPTIVE COMPANIES 2013

Our fourth annual list of companies around the world whose innovations will reshape markets.

It might be easier to explain the 50 Disruptive Companies project by starting with what it is not. It is not a quantitative assessment; we don't think R&D spending or numbers of patents and new products necessarily reveal what's most meaningful about a company's innovative power. It also is not a ranking. We don't mean to suggest that any of these 50 companies is more important or better than the others.

Instead, this package is meant to capture the rich variety of ways that innovations get commercialized. Each company on this list has done something over the past year that will strengthen its hold on a market, challenge the leaders of a market, or create a new market. As we detail in four feature stories and three CEO Q&As in this package, some of these companies, like the thermostat maker Nest, have burst forth with a breakthrough product, and the question now is what the next one will be. Others, like the battery startup Ambri, are still on the verge of their breakthrough. Then there are startups like Pinterest that still have to figure out their business model, and long-established companies like Xerox and Microsoft that have managed to change how their customers think of them. And some members of this group are opening up opportunities by greatly expanding the use of existing technology—such as the Chinese genomics research company BGI. (To learn more about all 50 companies, go to www.technologyreview.com/tr50.)

The pace of technological change is brutal. Even Apple, which we have selected for this package four years in a row, has to scramble. We think TV will be the product that returns it to the list next year, but there are hardly any guarantees. Only 15 of these 50 companies were also here last year. *—Brian Bergstein*

ENERGY & MATERIALS

28 ▶

ABB

NEW

PUBLIC | **FOUNDED:** 1883

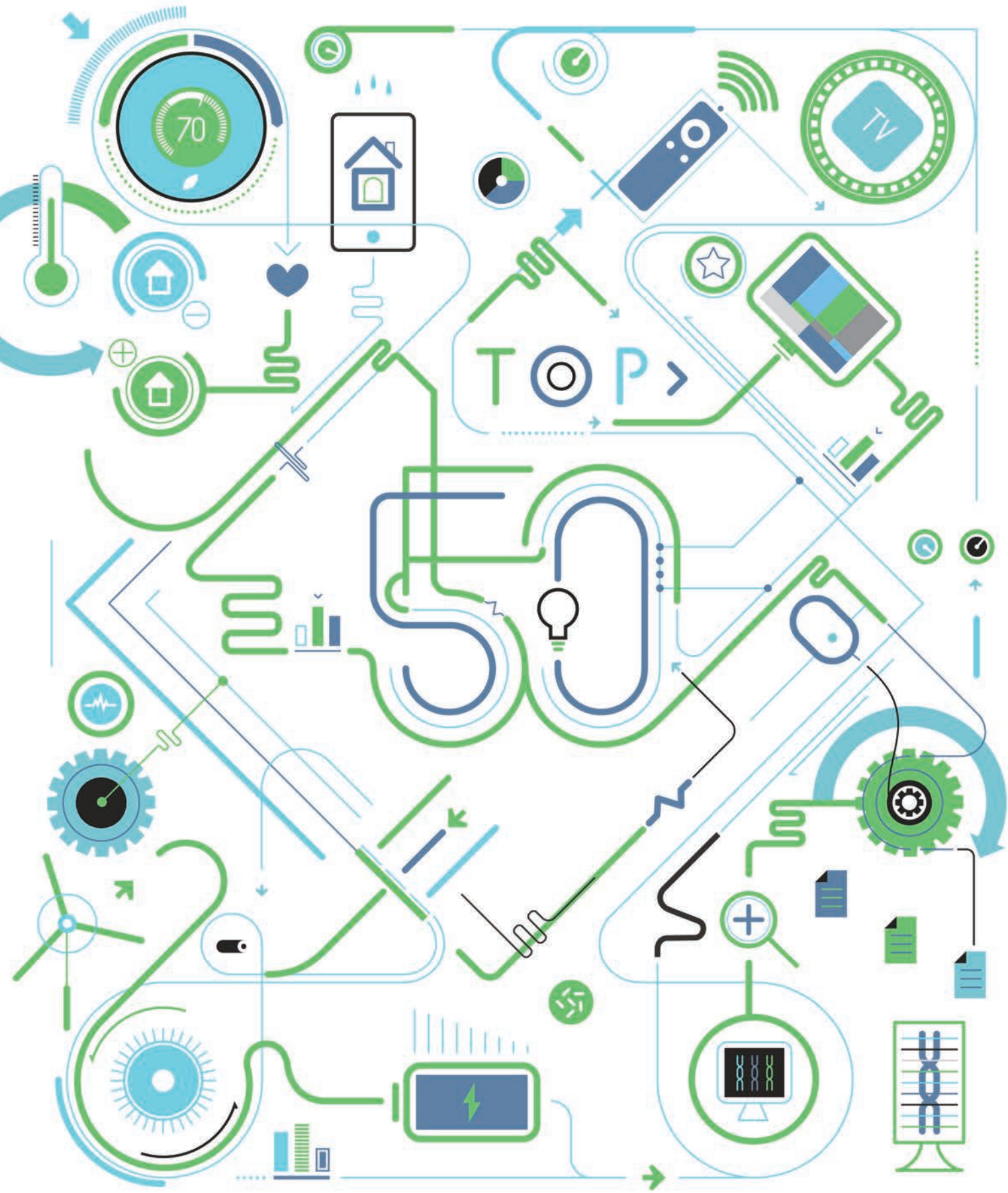
Perfecting a circuit breaker for high-voltage DC lines—a crucial step for widespread use of renewable energy.

Alta Devices

PRIVATE | **FOUNDED:** 2008

Advancing ultra-efficient solar. The military will use Alta's flexible sheets to provide portable power to drones and soldiers.

Illustration by Leandro Castelao


70
TV
TOP

INNOVATION THROUGH DESIGN

BY TOM SIMONITE PHOTOGRAPH GABRIELA HASBUN

Two men who created the iPod and iPhone founded **Nest** and injected new technology into the humble thermostat. Now they have their sights on the rest of your house.

In 2007, Tony Fadell believed he could see the future. He was an Apple executive who had created the iPod and was a leading figure on the team that had worked on the iPhone, which the company was about to launch. He knew people would soon form attachments to the Internet-connected computers they carried in their pockets, and he kept thinking about that as he started another major project: building an energy-efficient dream home near Lake Tahoe.

"I said, 'How do I design this home when the primary interface to my world is the thing in my pocket?'" says Fadell. He baffled architects with demands that the home's every feature, from the TV to the electricity supply, be ready for a world in which the Internet and mobile apps made many services more responsive. When it came to choosing a programmable thermostat for his expensive eco-friendly heating, ventilation, and air conditioning (HVAC) system, Fadell blew a gasket: "They were 500 bucks a pop, and they were horrible and doing nothing and brain-dead. And I was like, 'Wait a second, I'll design my own.'"

Fadell, who soon left Apple at the age of 40, became convinced that his thermostat needed to be built like a smartphone and controlled from one. He wanted it to be smart enough to learn his routine and to program its own schedule accordingly, or to switch off automatically if he went out. A thermostat, he thought, could do that if it was really a small computer connected to the Internet. As he planned the features and design in his head, Fadell began to believe that his vision would appeal to other people too, even if their homes were more ordinary. With about 10 million thermostats sold in the United States every year, it could be a lucrative business. And because thermostats typically control half the energy used in U.S. homes, a better-designed one could significantly reduce power consumption. He sought out Matt Rogers, a precocious 27-year-old who at the time led iPhone software development, and got him to leave Apple to cofound Nest.

Fadell's instincts turned out to be correct. Nest's first model, a striking stainless-steel-ringed disc with a circular display, went on sale in October 2011 to widespread acclaim. The HVAC industry, a sector as unexciting as the thermostats it sold, was astonished by the fresh ideas behind the device, which learned from its owners' behavior and could be controlled with a polished mobile app. The company released a second, more advanced thermostat in October 2012, and says sales of the two models have been brisk. The $250 product has kept owners from using 225 million

ENERGY & MATERIALS 30 ▶

Ambri NEW
PRIVATE | FOUNDED: 2010
Making a battery for storing energy on power grids. Its molten electrodes quickly absorb large amounts of electricity.

Aquion Energy NEW
PRIVATE | FOUNDED: 2009
Beginning to sell a novel kind of battery that it can manufacture cheaply; utilities could use it for grid storage.

BrightSource Energy NEW
PRIVATE | FOUNDED: 2004
Opening the biggest solar plant where mirrors reflect light onto a tower to generate steam.

Corning NEW
PUBLIC | FOUNDED: 1851
Producing a new kind of glass that is thin and flexible yet strong enough to be used in touch-screen devices.

With computing and design savvy, Matt Rogers (left) and Tony Fadell may have done more than anyone else in Silicon Valley to reduce energy consumption.

kilowatt-hours of energy, the company estimates—saving around $29 million at average U.S. prices. This suggests that merely with elegant design and computing savvy, Nest might be having more impact than other Silicon Valley ventures trying to deliver on the promise of "clean tech." Now the company is preparing to release another product. Details are scarce, but it seems that Fadell's thermostat epiphany has launched a technological campaign that will make every part of your home more intelligent.

Reprogramming

Fadell has the energy and ready smile of a late-night talk show host, and a voice that is permanently loud. Rogers is quieter and more technically focused. The pair appear to be having enormous fun sweating the details of what is, at its core, just an on-off switch. They burst into a meeting room at Nest's unremarkable offices in Palo Alto like two boys coming in from playing in the yard, breathless, in high spirits, and completing one another's sentences. Between them, they have had significant roles in creating two of the most iconic technology products of recent history, the iPod and iPhone—devices notable not only because they are useful and fashionable, but because they introduced genuinely new technological ideas. Rogers and Fadell have done the same at Nest, delivering a product that is both easier to use and more powerful than those that came before. That approach has helped them make the thermostat, historically a product bought and installed by contractors, into something people buy for themselves in the same stores where they get gadgets like phones and tablets.

For half a century, the state of the art in home energy controls has been the programmable thermostat. The theory is that if people can schedule when their heating and cooling systems will kick in, they don't have to waste energy by running the system at all times to be assured of comfortable temperatures when they wake up or return from work. But the HVAC industry has made programmable thermostats difficult to use, with unintuitive dials and sliders and cramped displays. Citing such "user interface issues," the Environmental Protection Agency removed programmable thermostats from its Energy Star certification program in 2009. Studies showed that they didn't reliably save energy; in fact, because many people end up switching their system on and off manually, programmable thermostats might cause most people to use more energy, says Kamin Whitehouse, a computer science professor at the University of Virginia. "People have a really hard time setting accurate schedules for their lives," he says.

The Genealogy of Nest

The iPod beat rivals with an appealing interface and easy-to-use companion software.

The iPhone popularized the idea of apps as a way to remotely control other things.

The Nest thermostat combines streamlined hardware with controls on a smartphone app.

When faced with a problem like this, many technologists would seek technical solutions. Fadell and Rogers thought instead about simplifying the device. "We started with the basic principle that 99.9 percent of the time, the only thing that you do is turn it up or down," Fadell says. "So what's the simplest form? A knob or a dial." More complex functions, such as setting a schedule, could be executed more easily through a mobile app. That freed his designers from having to accommodate the many buttons that appear on other programmable thermostats. The Nest became nothing more than a compact stainless-steel cylinder that you can turn once it's fixed to the wall.

Fadell and Rogers have made sure that at every stage of installing and operating a Nest thermostat, you discover that potential problems have been solved for you. When you attach the device to a wall, there's no need to drill holes or use plastic anchors to hold any screws. Nest's engineers reviewed every screw on the market and then invented their own, with wide-spaced threads that can bite wood or powdery drywall without making it crumble. The device powers itself by leeching electricity from the control wires that connect it to your HVAC system, a feat that makes Rogers chuckle at his engineers' audacity. Short- and long-range infrared sensors allow the device to light up when you approach and dim when you walk away—and to figure out that it was you, not the cat, who just went out, meaning it's time to turn down the heat. Perhaps the biggest reminder of the thermostat's intelligence comes a few days after installation, when you reach out to adjust the temperature and find that it has preëmpted you by learning from your earlier changes. "Think of a normal thermostat. Everyone turns it up, turns it down, a couple of times a day—that's a pattern we can infer from," says Fadell. "Instead of changing it fifteen hundred times a year, do it 10 or 20 times and the Nest thermostat can learn from that."

Fadell can deliver animated monologues about products that don't meet his ideals, an aspect of his personality that was prob-

ENERGY & MATERIALS

Dow Chemical NEW
PUBLIC | **FOUNDED:** 1897

Commercializing roof shingles that incorporate photovoltaic materials and thus double as cheaply installed solar panels.

General Electric
PUBLIC | **FOUNDED:** 1890

Helping utilities make use of wind and solar. A new GE gas turbine ramps up quickly when greener power isn't available.

Nest NEW
PRIVATE | **FOUNDED:** 2010

Marketing a thermostat that learns users' temperature preferences and maximizes efficiency as it implements them.

Philips NEW
PUBLIC | **FOUNDED:** 1891

Making efficient LED light bulbs affordable and more useful. One new bulb can be controlled by phones and tablets.

ably strengthened by years of working closely with Steve Jobs. But he also remains open to taking instruction from hard data, drawing on evidence collected from Nest thermostats, customer surveys, and a group of around 1,000 customers whose thermostats are used to test new features. For example, Nest thermostats originally adjusted themselves to an energy-conserving setting in the morning two hours after detecting that human activity in a home had stopped. They waited that long in case the owner soon returned home. But anonymous data from Nest thermostats revealed that people reliably stayed out for quite a while when they left in the morning. So the company sent a software update to all the thermostats to take that into account. Now the devices turn themselves down after just 30 minutes.

Such responsiveness to data from users isn't a quality typically found in the HVAC industry, which is dominated by a few large companies, such as Honeywell and Venstar, that sell to distributors and dealers, not consumers. It's an approach more commonly found in Silicon Valley companies, reflecting the fact that Nest is staffed with dozens of engineers who helped Apple build the iPod and iPhone. Rogers's former computer science professor Yoky Matsuoka, a winner of a MacArthur genius award, leads Nest's algorithms group. As a result, if you were drawing the Nest thermostat on a technological evolutionary tree, it would be an offshoot of the smartphone line. Rogers says, "Tear apart a Samsung smartphone—it's going to have a lot of the same components." In another echo of the mobile computing business, where the biggest players are locked in court battles over patents, Honeywell sued Nest for patent infringement a year ago. "They're one of the biggest companies in the world, and they feel threatened by a 150-person startup," says Rogers. "That's amazing."

Soft Power

Nest is being watched by green-tech researchers and investors who believe it may lead a new wave of technologies that can significantly reduce power use in homes, which account for about 10 percent of U.S. energy consumption. The government allocates tens of millions of dollars per year for programs that reduce energy use in residential buildings. But many home improvements, such as insulation and storm windows, cost thousands of dollars per house and deliver energy savings comparable to what a better thermostat can generate for far less money, Whitehouse says.

Nest says that a home with its product will save $173 per year in electricity and heating costs compared to a home with an unprogrammed thermostat, depending on local climate and other factors—allowing it to pay for itself in under two years. (When the device appears in Europe, the payback time will be significantly faster because energy is more expensive there.) Most savings flow from the system's ability to detect when the house is empty and learn its owner's preferences, but Nest also saves energy by figuring out how to minimize the use of the air conditioning's chiller and maximize the use of the fan. It also coaches people to use less energy; when consumption falls, they'll see a green leaf icon on the thermostat and its mobile and Web interfaces. That leaf won't appear if the energy use fell because of a shift in the weather. And Nest moves the goalposts so people must cut usage further to keep seeing the leaf.

Nest's ability to change how people consume energy also appeals to utilities, because the device can smooth out spikes in usage. Eventually, the thermostat's Internet connectivity could allow utilities to introduce smarter versions of "demand response" programs, in which customers get a discount in return for letting their utility adjust their thermostat in times of extremely high usage. Reliant, a utility in AC-dependent Texas, recently started bundling a free Nest thermostat with one of its plans.

Clearly, Nest's thoughtful engineering could be applied elsewhere in the home, and its founders acknowledge that they plan to build more than just thermostats. "We have one of the best teams in the industry," says Rogers—meaning Silicon Valley rather than the HVAC business. "They're here for more than just one product."

But Nest mimics Apple's strict secrecy. My visit was limited to the sparse lobby and a meeting room just inside the front door because, as the director of communications put it, the company was on "lockdown" while a new product was developed. When pressed, Fadell dismissed a suggestion that it would be logical to expand into "home automation," products today mostly pitched at enthusiasts that allow home appliances and lighting to be controlled remotely. "I'm not here to impress geeks," he says, but to make simple home technology "empowering for everyone."

The only thing clear about Nest's future is that the thermostat, seriously as it was taken, was only a warmup act. The iPod Fadell created at Apple was the first of a series of products that reinvented the company, says Peter Nieh, who led the venture fund Lightspeed's investment in Nest. "[Then] there was iPhone and much more. The thermostat is the iPod. It's the beginning." T

Tom Simonite is the senior IT editor at MIT Technology Review.

INTERNET & DIGITAL MEDIA

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Semprius NEW

PRIVATE | **FOUNDED:** 2005

Using a novel method of concentrating sunlight through tiny lenses to boost the efficiency of solar power.

Siemens

PUBLIC | **FOUNDED:** 1847

Developing batteries and wind technologies that will be crucial in Germany's plan to rely more heavily on renewable power.

Aereo NEW

PRIVATE | **FOUNDED:** 2011

Streaming local TV programs to mobile devices, filling a void left by broadcasters who have essentially ignored the Internet.

Coursera NEW

PRIVATE | **FOUNDED:** 2011

Making college courses available free online and developing ways to adjust them to students' individual needs.

STEVE BALLMER

The Microsoft CEO explains the strategy behind his company's most ambitious and strangest major product.

Q+A

Windows 8 is radically different from any previous version of the Windows operating system. Designed to run on smartphones, tablet computers, laptops, servers, and even supercomputers, Windows 8 presents its users with virtually the same interface on any device. The response to this approach has been mixed: some critics have praised the operating system's gorgeous graphic design and daring indifference to Microsoft's past; others are baffled (see our own review on page 76). Jason Pontin, *MIT Technology Review*'s editor in chief, spoke to Microsoft's chief executive, Steve Ballmer, about what Windows 8 means for his company.

Seeing the same graphical user interface across platforms is a wondrous thing, but it's also a little like seeing a bear on a bike. Why do it at all?
Increasingly, people access the same content and services from multiple devices or use more than one device at a time. [Having] the same look and feel shortens the learning curve and creates a more seamless user experience.

In order to demonstrate to customers and original equipment manufacturers (OEMs) the possibilities of the new interface, Microsoft was compelled to develop its first computer, the Surface tablet. Are you pleased with the sales of Surface?
I'm super-glad we did Surface. I think it is important—and not just for Microsoft but for the entire Windows ecosystem—to see integrated hardware and software.

Does that mean that Surface is a real business, and that you intend to be a manufacturing company in a meaningful way?
Surface is a real business. In an environment in which there's 350 million PCs sold, I don't think Surface is going to dominate volume, but it's a real business.

Do you think Microsoft has gotten better at figuring out what the user wants? You won't deny that you've experienced a few challenges in making consumer products.
Oh, I don't know. Our number-one thing is supplying products to consumers. That's kind of what we do. Sixty-five percent of all PCs go to the consumer, not to the enterprise. Seventy percent of all Office suites go to the consumer, not the enterprise. One hundred percent of all Xboxes go to the consumer, not the enterprise. Now, we've monetized the enterprise better than the consumer, there's no question about that. And there's no question that there are things that we have done for both the consumer and the enterprise that we would like to improve. So I'm not trying to push back. I'm merely trying to highlight that we really are very involved in both. We're building new capabilities to give the consumer what the consumer wants. Take pen computing [the use of a stylus on a tablet]: I think it's fair to say we've been talking about pen computing for years, but it was hard to do that with OEMs who were not equally incentivized. Now we're trying to lead a little bit with Surface Pro.

So is there a lack of understanding, or in some cases do I wish our execution had been better? I would say the latter. In cases where we've embraced end-user needs and really sort of dived in, like the things that we've done with Kinect and the Xbox, I think we've done a heck of a job.

I understand Google's vision for the future of computing. I know what Apple stands for. I used to understand what Microsoft stood for. I no longer know. What's your vision for the company?
I would simply say we're about defining the future of productivity, entertainment, and communication—in the new world [where] software is going to have to come in kind of an integrated form. Or at least a well-designed form that includes cloud services and devices.

And is that why Windows 8 is important? Because, for the first time, Microsoft is delivering an "integrated" experience across all important devices with software delivered from the cloud?
If you want to do productivity, communications, and entertainment, you're going to do it on multiple devices, and you have to do it in a coherent and consistent way for the user. You've got to support the different input modalities. The living room is different from the phone, and productivity at the desk is different from productivity on the go. So, yes, Win8 and the Win8 family of devices are super-important for supporting our broad vision.

ROLF VENNENBERND/EPA/CORBIS

INDUSTRIAL-SCALE GENOMICS

BY CHRISTINA LARSON PHOTOGRAPHS PHILIPP ENGELHORN

Sequencing a complete human genome may soon cost less than an iPhone. Will China's **BGI-Shenzhen** decode yours?

When he was 17 years old, Zhao Bowen dropped out of Beijing's most prestigious high school. Like many restless young people in China, he headed south to Shenzhen, the country's factory capital, for a job. As a teenage science prodigy, however, he wasn't bound for an assembly-line floor; instead, he was on his way to the world's largest production center for DNA data. Now, a few years later, in a retrofitted shoe factory that is the headquarters of BGI-Shenzhen, the 21-year-old is orchestrating an effort to decipher the genetic makeup of some 2,000 people—more than 12 trillion DNA bases in all.

BGI-Shenzhen, once known as the Beijing Genomics Institute, has burst from relative obscurity to become the world's most prolific sequencer of human, plant, and animal DNA. In 2010, with the aid of a $1.58 billion line of credit from China Development Bank, BGI purchased 128 state-of-the-art DNA sequencing machines for about $500,000 apiece. It now owns 156 sequencers from several manufacturers and accounts for some 10 to 20 percent of all DNA data produced globally. So far, it claims to have completely sequenced some 50,000 human genomes—far more than any other group.

BGI's sheer size has already put Chinese gene research on the map. Those same economies of scale could also become an advantage as comprehensive gene readouts become part of everyday medicine. The cost of DNA sequencing is falling fast. In a few years, it's likely that millions of people will want to know what their genes predict about their health.

BGI might be the one to tell them. The institute hasn't only initiated a series of grandly conceived science projects. (In January, it announced it had determined the DNA sequence of not one but 90 varieties of chickpeas.) It's also pioneered a research-for-hire business to decode human genomes in bulk, taking orders from the world's top drug companies and universities. Last year, BGI even started to install satellite labs inside foreign research centers and staff them with Chinese technicians.

BGI's rise is regarded with curiosity and some trepidation, not just because of the organization's size but also because of its opportunistic business approach (it has a center for pig cloning, dabbles in stem-cell research, and runs a diagnostics lab). The institute employs 4,000 people, as many as a midsize university—1,000 in its bioinformatics division alone. Like Zhao, most are young—the average age is 27—and some sleep in company dormitories. The average salary is $1,500 a month.

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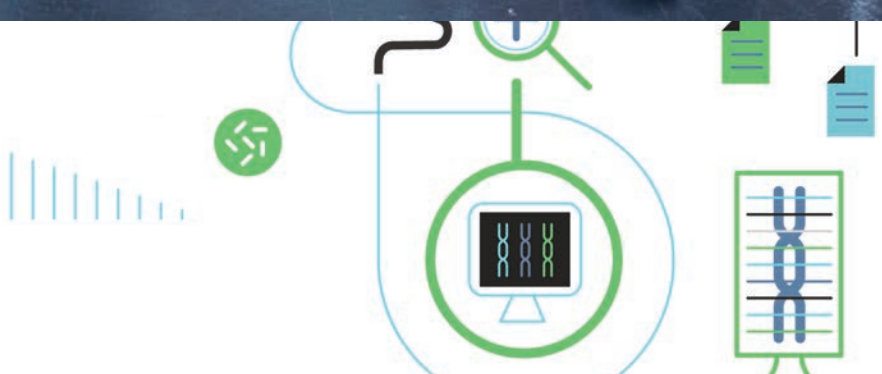
CrowdStrike NEW
PRIVATE | FOUNDED: 2011
Introducing a new kind of antivirus software that's better at detecting attacks and identifying their sources.

Facebook
PUBLIC | FOUNDED: 2004
Figuring out how to correlate online and offline activity, which should lead to novel advertising methods.

Factual NEW
PRIVATE | FOUNDED: 2007
Collecting and analyzing big data sets to create stores of knowledge that can inform many kinds of software.

InMobi NEW
PRIVATE | FOUNDED: 2007
Challenging Google and Apple in the market for mobile ads. InMobi sells, distributes, and helps make the ads.

Wang Jian (left) is BGI-Shenzhen's president; Zhao Bowen directs a group studying the genetics of IQ. The Chinese institute employs 4,000 people.



Ten years ago, the international Human Genome Project was finishing up the first copy of the human genetic code at a cost of $3 billion. Thanks to a series of clever innovations, the cost to read out the DNA in a person's genome has since fallen to just a few thousand dollars. Yet that has only created new challenges: how to store, analyze, and make sense of the data. According to BGI, its machines generate six terabytes of data each day.

Zhang Yong, 33, a BGI senior researcher, predicts that within the next decade the cost of sequencing a human genome will fall to just $200 or $300 and BGI will become a force in assembling a global "bio-Google"—it will help "organize all the world's *biological* information and make it universally accessible and useful."

Some outsiders, however, question whether BGI is anything more than biology's version of Foxconn, the giant assembler of iPads and other gadgets designed elsewhere, whose largest factory, employing some 240,000 workers, is also in Shenzhen. While BGI has done important science—a recent paper on sequencing the bacteria in the human gut made the pages of *Nature*—it's seen more as a mass producer of data than as an instigator of original research that can explain what the results mean.

"BGI has scaled up very impressively," says Eric Lander, director of the Broad Institute in Cambridge, Massachusetts, which operates the largest academic DNA sequencing center in the United States. "But I think that absolute scale is much less important than what you do with it."

$3,000
Price quoted by China's BGI to completely sequence a person's DNA.

"Don't Worry, Be Happy"

BGI's president, Wang Jian, 59, cofounded the company with Yang Huanming, 61, in 1999. They managed to persuade the leaders of the Human Genome Project, then in full swing, to let them handle 1 percent of the work, making China the only developing nation to play a major role. In 2002, BGI turned heads by publishing the complete sequence of the rice plant in *Science*. Research in the national interest has been a BGI mainstay: it decoded the DNA of the giant panda, and it discovered the genetic mutation that makes Tibetans so well suited to life at high altitudes. Outside work hours, Wang is known for having scaled Mount Everest in 2010. ("It's a national park—so what? Not a big deal," he says.)

A quirky, informal logic governs BGI. That has made it a puzzle to observers; it's very different from hierarchical Chinese institutions, where credentials and connections can matter most. Deputy director Xu Xun, 29, who oversees the 1,000-strong bioinformatics group, says it's why BGI attracts so many talented young people. "You get [to play a role in] a lot of exciting things here," he says. In 2010, *Nature* cited BGI's model in an editorial questioning whether scientists really need PhDs. Xu himself came to BGI after abandoning his PhD studies. He's what's known admiringly around the company as a "leaver"—impatient with school and eager for real-world experience.

In Wang's cubicle, which is in the middle of a long bay of identical blue cubicles backed by windows overlooking a mountainside construction site, is a hand-signed letter from Bill Gates announcing a partnership on agricultural genomics that BGI and the Gates Foundation agreed to last fall. "He loves the dropouts," Wang says of the Microsoft chairman. He grins and then sings a few bars from Bobby McFerrin's "Don't Worry, Be Happy," adding, "I love that song."

BGI bills itself as China's first "citizen-managed" research institute. With strong political support from Beijing, it became part of the vaunted Chinese Academy of Sciences in 2003. But it was an uneasy fit. The conservative academy limits the size of its institutes, yet BGI was on a hiring spree, and it was thumbing its nose at university credentials, too. In 2007, the government of Shenzhen offered BGI $12.8 million to move to the port city and become an independent institute.

Today, Wang says, only about 10 percent of BGI's revenue comes from government projects—and that's largely from local municipalities, not from Beijing. The rest is a mix of grants, some anonymous donations, and fees from clients, including as little as $3,000 to $4,000 to sequence a human genome. Since BGI is private and doesn't release financial details, it's hard to know how all the numbers line up.

What's more, even though it's a nonprofit, BGI operates several businesses. That's left Westerners guessing at the true nature of the Chinese institute. Wang says they shouldn't worry. "We like science; we need money. We put the two things together," he says.

INTERNET & DIGITAL MEDIA

MLB Advanced Media NEW
PRIVATE | **FOUNDED:** 2000
Expanding the delivery of live baseball and other sports video to mobile devices.

Path NEW
PRIVATE | **FOUNDED:** 2010
Demonstrating an alternative business model for social networking: selling users extra services.

Pinterest NEW
PRIVATE | **FOUNDED:** 2009
Creating a social network centered on collecting and finding images of desired products and experiences.

Safaricom
PUBLIC | **FOUNDED:** 1997
Extending the use of the mobile currency M-Pesa in Kenya. Its new mobile lending service challenges banks.

"I use my left hand to make money and my right hand to do basic research." At a recent biotechnology conference in Shenzhen, cosponsored by BGI, Wang gave the opening presentation. One of his slides read: "World-Class Science = World-Class Business."

Thousands of Genomes

In its scientific work, BGI often acts as the enabler of other people's ideas. That is the case in a major project conceived by Steve Hsu, vice president for research at Michigan State University, to search for genes that influence intelligence. Under the guidance of Zhao Bowen, BGI is now sequencing the DNA of more than 2,000 people—mostly Americans—who have IQ scores of at least 160, or four standard deviations above the mean.

Technicians at BGI's headquarters in Shenzhen, China, prepare blood samples (left) to feed into automated DNA sequencing machines (below).

The DNA comes primarily from a collection of blood samples amassed by Robert Plomin, a psychologist at King's College, London. The plan, to compare the genomes of geniuses and people of ordinary intelligence, is scientifically risky (it's likely that thousands of genes are involved) and somewhat controversial. For those reasons it would be very hard to find the $15 or $20 million needed to carry out the project in the West. "Maybe it will work, maybe it won't," Plomin says. "But BGI is doing it basically for free."

From Plomin's perspective, BGI is so large that it appears to have more DNA sequencing capacity than it knows what to do with. It has "all those machines and people that have to be fed" with projects, he says. The IQ study isn't the only mega-project under way. With a U.S. nonprofit, Autism Speaks, BGI is being paid to sequence the DNA of up to 10,000 people from families with autistic children. For researchers in Denmark, BGI is decoding the genomes of 3,000 obese people and 3,000 lean ones.

Beyond basic science, BGI has begun positioning itself as the engine of what's expected to be a boom in the medical use of genome scans. In 2011, for instance, it agreed to install a DNA analysis center inside the Children's Hospital of Philadelphia, a leading pediatric hospital. Ten bioinformatics experts were flown in from Shenzhen on temporary visas to create the center, which opened six months later with five sequencing machines.

As the technology enters clinical use, the number of genomes sequenced in their entirety could catapult into the millions per year. That is what both the Philadelphia hospital and BGI are preparing for. "They have the expertise, instruments, and economies of scale," says Robert Doms, chairman of the children's hospital. He says it will pay BGI a fee for each genome it sequences, and will offer the service to parents of young patients with undiagnosed diseases. The hospital will also be developing new types of genetic tests, an area where the Chinese agree they have much to learn. Although BGI operates a genetic testing center in China, the degree of regulation seen in the United States is new to its researchers. "It's a whole additional level of rigor," says Doms.

BGI is also proving it can be nimble in seeking business opportunities. Last fall, it made a surprise bid to purchase a faltering U.S. company, Complete Genomics of Mountain View, California. The company operates a complex technology for sequencing human DNA; in 2012 it accounted for perhaps 10 percent of all human DNA data generated globally. But it was losing money.

BGI's bid to buy the company, for the fire-sale price of $118 million, has stirred competitive worries in the U.S. The main supplier of DNA sequencing instruments, Illumina, tried to break up the deal with a counter-bid and appealed to Washington to block the takeover. Letting BGI snap up the company would be equivalent to selling China the "formula for Coke," said Illumina's CEO, Jay Flatley. Flatley cautioned that the Chinese, until now dependent on U.S. machinery, could dominate next-generation technology—and that they could even somehow make "nefarious" use of American DNA data flowing through their computer servers by the terabyte. U.S. regulators have dismissed the national security concerns, and approval of the deal is pending.

BGI's leaders know that resistance to its expansion is real, but they shrug off the concerns. The joke in the cubicles is that if BGI were truly a tool of Beijing, it would probably have nicer office space. More matter-of-factly, Xu, the head of the bioinformatics team, says of the acquisition: "This is a good technology. The company is bankrupt; we think it's a good chance to do something."

Wang, the Everest climber, is still frequently asked to explain BGI's strategy and its intentions. He says to think of a wandering migrant worker—looking for opportunity and occasionally irritating the authorities. That is what BGI is like. But its only core mission is to do work that will be socially useful, he says: its strategy is to "do good."

Christina Larson is a writer based in Beijing.

COMPUTING & COMMUNICATIONS

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Tencent
NEW
PUBLIC | **FOUNDED:** 1998

Dominating Chinese social media. The company's version of Twitter is hugely influential in political affairs.

Amazon
NEW
PUBLIC | **FOUNDED:** 1994

Cranking up the appeal of purchasing goods online by offering same-day delivery in some places.

Apple
PUBLIC | **FOUNDED:** 1976

Improving displays by extending its Retina technology from small screens to MacBooks and iPads.

ARM Holdings
PUBLIC | **FOUNDED:** 1990

Becoming a bigger factor in computing as it expands from mobile chip designs into tablet, PC, and server processors.

URSULA BURNS

Xerox's CEO wants to use technology to shake up the staid business-services market.

Q+A

Xerox dominated the office of yesterday with its copiers, laser printers, and fax machines. Now Ursula Burns is trying to strengthen its role in the offices of tomorrow. Since becoming CEO in 2009, she has increased Xerox's sales of IT-related services, like processing health insurance claims and managing customer-service call centers. Nevertheless, Burns—a mechanical engineer who has worked at Xerox since an internship in 1980—told *MIT Technology Review*'s deputy editor, Brian Bergstein, that the company isn't straying from its technological roots.

The field of business services does not necessarily reward technological innovators. Isn't it largely driven by how well you lower a client's costs?
It is. The start of BPO [business-process outsourcing] was basically taking the mess of somebody else and doing it for less. Let's take business processes that are identical—everybody has to answer calls—and if you can [handle such things for many companies], then you can use scale to your advantage. Then it went to "Can we move it to lower-cost areas and lower-cost people?" So it became labor arbitrage. And where we are now with BPO, and this is the most exciting part about Xerox, is that the next big step is not in trying to go to the next cheapest place.

Why? Have we reached the lowest that labor costs can go?
Not yet, but we're getting there. The next big step comes in technology. So if you have 100 people answering the phone and they take 10 calls an hour, can you get it such that you have 100 people that take 15 calls an hour? Can you apply technology to make it such that instead of taking six or seven weeks to train a person in a complex call, you make it take two weeks, or one week? Can you make it such that—most calls are recorded—you can look at the calls after and figure out key things, see patterns via big data? And can you actually apply that?

What's an example of a services deal you won because of technology you had?
Working with municipalities in California on better parking. Parking is a pain in the ass. And it doesn't get enough money for the value. In the middle of the day [cities] want to charge a whole lot of money for parking on the street. We developed congestion-parking solutions such that [cities] can vary price. So you're driving around, and—some of this is still in trial mode—you can get a bing on your phone that says "There's a parking spot a block over," and it will charge you the appropriate amount. This is all driven by technology from our Grenoble labs [in France].

In the 1970s, PARC, Xerox's Silicon Valley lab, invented computing breakthroughs that languished because they didn't fit into Xerox's copier business. How do you keep your researchers focused now?
It's all about themes. Even if [Xerox's customers] are in many different lines of work, one of the themes is that they [all] have a lot of information, and a lot of it has to be processed, and generally by people. A large amount of what we do is to try to figure out a way we can make a process operate via technology like a human would operate it, without the inefficiencies and the errors and moods.

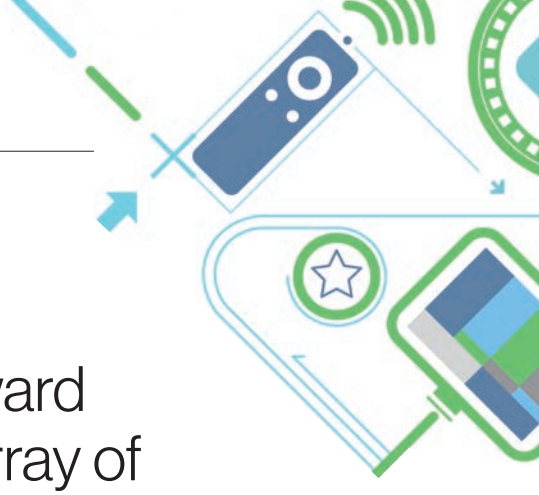
Why have you cut Xerox's spending on research, development, and engineering?
Primarily because of what we are RD&Eing. When you are a builder of things, one of the most expensive pieces of RD&E is the building of the thing—the prototyping. If you look at a software company's RD&E, it's [often] counted in cost of goods or packaged in the price of a deal. You develop a solution on behalf of a client and it's not called "research." It's not a capital expense.

My big balance right now is to make sure we don't spoil ourselves into believing *all* of the innovation will come at the client site. I want to think even beyond that. That's where the labs have to jump to.

How much longer will Xerox still be selling copiers and printers?
For as long as the customer needs them, which will still be a while.

Well, will offices still be churning out lots of paper in 2020? 2030?
In 2020, oh yeah, there will still be a lot of paper. People like it. You fold it up, you put it in your shirt. Until somebody develops a technology that [has such] benefits in some other form, paper will be here. I was just looking at cars. They still hand me brochures! It's really important. And by the way, when I do it on my iPad, it's not as easy. So until they figure out a way to make it that easy, paper will be there and I'll still be printing.

Photograph by Julie Bidwell



REDEFINING A MARKET

BY ROBERT D. HOF ILLUSTRATIONS SHOUT

Television viewers fumble with awkward remote controls and crave a richer array of on-demand programming. It's time for **Apple** to step in and disrupt the TV business.

Steve Jobs couldn't hide his frustration. Asked at a technology conference in 2010 whether Apple might finally turn its attention to television, he launched into an exasperated critique of TV. Cable and satellite TV companies make cheap, primitive set-top boxes that "squash any opportunity for innovation," he fumed. Viewers are stuck with "a table full of remotes, a cluster full of boxes, a bunch of different [interfaces]." It was the kind of technological mess that cried out for Apple to clean it up with an elegant product. But Jobs professed to have no idea how his company could transform the TV.

Scarcely a year later, however, he sounded far more confident. Before he died on October 5, 2011, he told his biographer, Walter Isaacson, that Apple wanted to create an "integrated television set that is completely easy to use." It would sync with other devices and Apple's iCloud online storage service and provide "the simplest user interface you could imagine." He added, tantalizingly, "I finally cracked it."

Precisely what he cracked remains hidden behind Apple's shroud of secrecy. Apple has had only one television-related product—the black, hockey-puck-size Apple TV device, which streams shows and movies to a TV. For years, Jobs and Tim Cook, his successor as CEO, called that device a "hobby." But under the guise of this hobby, Apple has been steadily building hardware, software, and services that make it easier for people to watch shows and movies in whatever way they wish. Already, the company has more of the pieces for a compelling next-generation TV experience than people might realize.

And as Apple showed with the iPad and iPhone, it doesn't have to invent every aspect of a product in order for it to be disruptive. Instead, it has become the leader in consumer electronics by combining existing technologies with some of its own and packaging them into products that are simple to use. TV seems to be at that moment now. People crave something better than the fusty, rigidly controlled cable TV experience, and indeed, the technologies exist for something better to come along. Speedier broadband connections, mobile TV apps, and the availability of some shows and movies on demand from Netflix and Hulu have made it easier to watch TV anytime, anywhere. The number of U.S. cable and satellite subscribers has been flat since 2010.

Apple would not comment. But it's clear from two dozen interviews with people close to Apple suppliers and partners, and with people Apple has spoken to in the TV industry, that television—the medium and the device—is indeed its next target.

COMPUTING & COMMUNICATIONS 42 ▶

Google
PUBLIC | **FOUNDED:** 1998

Running the most widely used smartphone software, which has greatly expanded the competition for devices.

IBM
PUBLIC | **FOUNDED:** 1911

Pushing the physical boundaries of computing with technologies including circuits that transmit data with light.

Intel
PUBLIC | **FOUNDED:** 1968

Surpassing rivals in the performance of mobile processors, even though it still trails badly in market share.

Kymeta
NEW

PRIVATE | **FOUNDED:** 2012

Developing relatively small antennas that replace satellite dishes so planes and trains can get better broadband service.

The biggest question is not whether Apple will take on TV, but when. The company must eventually come up with another breakthrough product; with annual revenue already topping $156 billion, it needs something very big to keep growth humming after the next year or two of the iPad boom. Walter Price, managing director of Allianz Global Investors, which holds nearly $1 billion in Apple shares, met with Apple executives in September and came away convinced that it would be years before Apple could get a significant share of the $345 billion worldwide market for televisions. But at $1,000, the bare minimum most analysts expect an Apple television to cost, such a product would eventually be a significant revenue generator. "You sell 10 million of those, it can move the needle," he says.

Cook, who replaced Jobs as CEO in August 2011, could use a boost, too. He has presided over missteps such as a flawed iPhone mapping app that led to a rare apology and a major management departure. Seen as a peerless operations whiz, Cook still needs a revolutionary product of his own to cement his place next to Saint Steve. Corey Ferengul, a principal at the digital media investment firm Apace Equities and a former executive at Rovi, which provided TV programming guide services to Apple and other companies, says an Apple TV will be that product: "This will be Tim Cook's first 'holy shit' innovation."

TVs could give Apple a way of entering or expanding its role in lines of business that are more profitable.

What Apple Already Has

Rapt attention would be paid to whatever round-edged piece of brushed-aluminum hardware Apple produced, but a television set itself would probably be the least important piece of its television strategy. In fact, many well-connected people in technology and television, from TV and online video maven Mark Cuban to venture capitalist and former Apple executive Jean-Louis Gassée, can't figure out why Apple would even bother with the machines.

For one thing, selling televisions is a low-margin business. No one subsidizes the purchase of a TV the way your wireless carrier does with the iPhone (an iPhone might cost you $200, but Apple's revenue from it is much higher than that). TVs are also huge and difficult to stock in stores, let alone ship to homes. Most of all, the upgrade cycle that powers Apple's iPhone and iPad profit engine doesn't apply to television sets—no one replaces them every year or two.

But even though TVs don't line up neatly with the way Apple makes money on other hardware, they are likely to remain central to people's ever-increasing consumption of video, games, and other forms of media. Apple at least initially could sell the screens as a kind of Trojan horse—a way of entering or expanding its role in lines of business that are more profitable, such as selling movies, shows, games, and other Apple hardware.

That's essentially the justification for the Apple TV product, the $99 hockey puck that streams TV shows and movies on demand for $1.99 and up. For most of its six years on the market, the device hasn't been a big seller. Nor have many of the other TV add-ons, such as Google TV or even TiVo. But Cook has upgraded the way he talks about Apple TV: in October he called it a "beloved" hobby, perhaps because sales had almost doubled, to five million units, in the previous fiscal year. One reason it's more appealing is that in July, Apple added Hulu Plus to the small list of Apple TV apps. That made it possible, for $8 a month, to watch current shows on demand the day after they air on TV.

But selling a TV set could also give Apple a way to enhance the role iPads and iPhones are playing in living rooms. Apps ranging

COMPUTING & COMMUNICATIONS

Leap Motion NEW
PRIVATE | **FOUNDED:** 2010

Bringing gesture control to any computer. Leap's $70 controller responds to pinches, grabs, and swipes in the air.

MC10 NEW
PRIVATE | **FOUNDED:** 2008

Pioneering stretchable electronics with applications in sports and medicine, like an impact-sensing skullcap.

Microsoft NEW
PUBLIC | **FOUNDED:** 1975

Combining traditional desktop computing with touch technology. Windows 8 could influence the PC and mobile markets.

Mozilla NEW
PRIVATE | **FOUNDED:** 1998

Bringing the smartphone revolution to more poor countries with Firefox OS, which is based on Web technology.

from Apple's own Remote to personalized programming guides such as NextGuide are turning them into far more capable portals into the TV than cable remote controls. In fact, Ben Reitzes, an analyst at the investment bank Barclays, believes that Apple's TV strategy actually revolves less around the TV set than around the iPad as universal remote. He thinks the appeal of an iPad remote would help maintain Apple's tablet dominance, especially as the company extends iPads to become a "central command" for lights, heating systems, and other features of the digital home.

A potentially much bigger advantage for Apple is a feature called AirPlay in the latest Mac and mobile iOS software. It allows whatever is showing on Macs, iPhones, and iPads to be "mirrored" to a TV set. Although not many iOS television apps support AirPlay yet, viewers can use Macs sold since mid-2011 to mirror shows from the free Hulu site, network websites, and even—perish the thought—pirate video sites. Suddenly, viewers can watch a lot of current shows on their HDTVs quickly and wirelessly—and, most important, without a cable subscription.

What Apple Still Needs

But Apple isn't likely to disrupt the TV business solely by helping people get around the traditional cable and satellite providers. Instead, it will try to work with them—and give them an incentive to come along. Stewart Alsop, a partner in the VC firm Alsop Louie Partners and a former member of TiVo's board, says Apple could use a tough-love approach: "Apple is the one company in the world that's powerful enough to take on monopolies and force them to change."

Making friends with them has proved to be Apple's most difficult challenge so far—and a solution is hard to discern. A few media conglomerates that run cable and broadcast channels, such as Walt Disney, Time Warner, and Viacom, remain extremely profitable. TV advertising generates $72 billion annually in the United States alone. Plus, the cable and satellite operators that distribute programming to homes gross $103 billion a year in pay TV subscriptions, sending $28 billion of that back to the media companies. Pay TV operators such as Comcast are also large Internet service providers, giving them influence over how far online TV services can go.

So unlike music labels before them—which were weakened by piracy and thus were more willing to grant Apple the right to sell individual songs for 99 cents apiece—they have no need to sell their content cheap. In particular, producers won't give Apple access to their live shows without a guarantee of the same big bucks they get from cable and satellite operators. The TV companies are wary of even letting Apple create a new TV user interface for their customers, the key to making an Apple television something special.

The classic Apple approach to such a situation would be to come up with a superior, or at least more elegant, product and force companies in related fields to play along. But Apple used to do that by having Steve Jobs charm and cajole recalcitrant partners. Jobs also understood the entertainment business and knew the players. He built Pixar into one of the world's most successful movie studios, then served on Disney's board after Disney bought Pixar in 2006. And even he struggled to persuade TV companies. CBS CEO Leslie Moonves, for one, said he rejected overtures in 2011 by Jobs himself for an Apple TV subscription service. Today, Eddy Cue, Apple's senior vice president of Internet software and services, is the company's most important TV dealmaker.

So how can Apple get more leverage and force the pay TV industry to deal? One possibility is that the troika of iPads, Apple TV, and the TV set—made by Apple or not—could bring about even more sweeping changes to make the television-watching experience more interactive. Google tried to do something similar two years ago with its Google TV service, but at least initially the results were too geeky, requiring a keyboard and clunky navigation. Its recently introduced voice-driven remote control feature, using Android smartphones and tablets, only underscores the fact that people want a less brain-taxing experience in the living room.

But a new generation of "dual-screen" apps could provide the best of both traditional TV and the Internet, says Jeremy Allaire, chairman of Brightcove, a provider of online video services. Major League Baseball's iPad app, for instance, plays a game on the TV through Apple TV while you check out relevant stats and chat with friends on your tablet. Essentially, says Allaire, whose company helps software developers create these apps, iPads and iPhones serve as the real brains of the TV.

Apple could also let people use voice-driven commands to find shows and change channels using Siri, its intelligent personal assistant. You could toss that annoying cable remote and just tell your TV what you want to watch. Moreover, Apple's iCloud storage service could be used as a digital video recorder in the sky, as Jobs hinted to Isaacson. Already iCloud can store TV shows bought on iTunes and feed them to any Apple device.

If such enhancements make Apple TV ever more useful, then "at some point, the growing Apple TV installed base will

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Nuance Communications NEW

PUBLIC | **FOUNDED:** 1992

Creating new applications for speech recognition technology, from cars to video games.

Rethink Robotics NEW

PRIVATE | **FOUNDED:** 2008

Broadening the use of robotics in manufacturing. Its robots are easily taught and can work safely alongside humans.

Samsung

PUBLIC | **FOUNDED:** 1938

Leading the market for smartphones and making a tablet that is one of the few credible challengers to the iPad.

Square

PRIVATE | **FOUNDED:** 2009

Streamlining transactions. A Square mobile app lets you pay for things just by speaking your name to a store clerk.

gain enough mass to become a viable distribution channel, an alternative to traditional cable TV," suggests onetime Macintosh executive Gassée, now a general partner at the venture firm Allegis Capital. "When this happens, someone will crack." That is, a cable channel such as ESPN will offer its must-have sports coverage on Apple TV, and others will feel forced to follow—thus paving the way for a credible Apple television.

Apple has also explored building a cable set-top box—possibly a souped-up Apple TV using a CableCard, a small card that plugs into a DVR or other TV device and allows subscribers to view cable channels without a separate box. Although it would be working within the current cable industry model, Apple would provide a more intuitive interface, like the iPad's, and users would be able to watch live and on-demand shows through an Internet-based DVR service.

This might work. Comcast and Time Warner Cable executives have said they're open to new program guide interfaces from Apple and other companies so long as cable subscribers keep paying them. Cable subscribers could be "authenticated" through Apple's set-top box, or eventually a TV, to prove they're subscribers—a system like the one HBO uses, for example, with the HBO Go app that streams its shows to mobile devices.

Jobs understood the entertainment business and knew the players, and even he struggled to persuade TV companies.

But Apple may not have time to wait for them to deal. Competition from Google (which is experimenting with a pay TV and Internet service in Kansas City), Amazon (which has a streaming video service and plans to produce original series), or Microsoft (whose Xbox gaming console is as much a video delivery device as a game machine) may force Apple to stake out territory in the living room more forcefully, and soon. Maybe, just maybe, a sleek Apple-designed flat screen, combined with a more elegant user interface, iPads serving as slick remotes, Apple's existing iTunes library, and shows from outside services such as Netflix and Hulu, would be compelling enough for consumers while Eddy Cue keeps doing lunch in Hollywood. "The reality from a consumer standpoint," says Piper Jaffray analyst Gene Munster, is that Apple "needs to revolutionize the interface and the design" before it can reorganize TV content. Munster expects to see an Apple television this November, at least two years after he initially predicted. "We don't need a nuclear event around content for an Apple television to be successful," he says.

It's worth noting that with its iPads and iPhones, Apple is already selling the TV screen of choice for a rising number of peripatetic viewers. You can't use these devices to watch everything you get on cable, but TV apps offer shows from CBS and HBO, some free, plus live baseball games and other programming. More than half of tablet owners under 35 watch TV on them at least weekly, according to a survey in August by the consulting firm Altman Vilandrie.

In other words, don't just think of an Apple TV as the big screen in the living room, or else you might miss where Apple really envisions the 75-year-old medium going next: everywhere. "Whatever it is, it's not going to be just on that big box," says Jeremy Toeman, CEO of Dijit, developer of the TV programming guide app NextGuide. Before long, he says, "everything you have with a screen will become a television set." Jobs may have "cracked" television, but Apple could blow it wide open.

Robert D. Hof, a former Silicon Valley bureau chief for BusinessWeek, *wrote about Google TV in January/February 2011.*

COMPUTING & COMMUNICATIONS

Vidyo
NEW
PRIVATE | **FOUNDED:** 2005

Threatening the likes of Cisco by using a compression technology to enable high-def video conferencing on smartphones.

VMware
NEW
PUBLIC | **FOUNDED:** 1998

Making cloud services more powerful with software-defined networking, a technology it gained by buying startup Nicira.

Xerox
NEW
PUBLIC | **FOUNDED:** 1906

Automating urban services. A Xerox system in Los Angeles changes the price of parking spots as demand fluctuates.

BIOMEDICINE 48 ▶

BGI
NEW
PRIVATE | **FOUNDED:** 1999

Sequencing more genomes than anyone else and becoming a worldwide provider of genome services.

Speakers Include:

Aaron Levie, Cofounder & CEO
BOX

Rick McConnell, President
AKAMAI

Muriel Médard, Professor
MIT

Michael Sippey, VP of Product
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BEN SILBERMANN

Pinterest's CEO says that crowds of people are better than algorithms at finding content that consumers care about.

Q+A

In 2012 the startup Pinterest became a peer of more established social sites by offering things that they didn't—an attractive design, a focus on images rather than text, and a mostly female population of users. On Pinterest, people use virtual "pinboards" to curate collections of images related to their hobbies and interests, discovering new items for their virtual hoards on the boards of friends and in the site's personalized recommendations. Tom Simonite, *MIT Technology Review*'s senior IT editor, recently spoke with Ben Silbermann, Pinterest's cofounder and CEO, about the company's popularity.

What was the need you were trying to fill when you created Pinterest?
We started making Pinterest around 2009, when there was a lot of attention being paid to social services that were focused on real-time text-based feeds like Facebook and Twitter. We felt the things that we enjoyed doing in the real world were hard to express in that format. The thing that was really exciting for us was that people started creating pinboards for things that they were actually going off and doing in their life. That early user base set the tone and the expectation that the way you use it is to get inspired and plan to do things, whether that was redecorating your home or planting a garden.

I think I've heard you think of that as closer to offline than online experience.
Not as much attention has been paid to discovering things online as has been to search. Discovery is exploration—you go through a series of things you're interested in and in that journey end up finding something you love and didn't know existed. That experience is very difficult [to replicate online], and in some ways the offline world has spent a lot more time iterating on that. People thought, "What should a window display look like?" "What should a catalogue look like?"

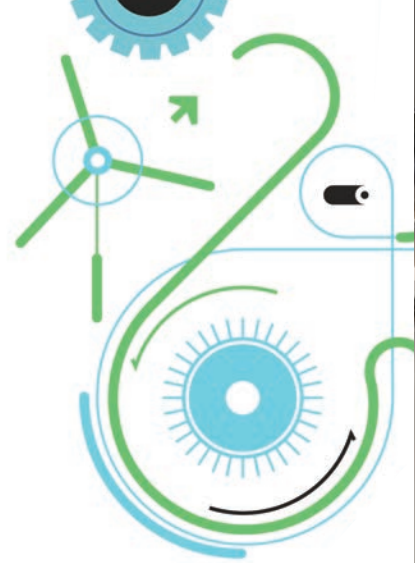
How does Pinterest's approach go about trying to solve that?
We often talk about Pinterest as like a human indexing machine. Google built these crawlers that would go out, and these amazing algorithms. We give people tools that let them organize in a way that makes sense to them, and in doing that they organize in a way that makes sense to other people. It just sort of respects our philosophy of how we want to achieve our mission, by helping people organize things. That organization is different than the approach you would take if you were only using machines.

Many people think or assume that Pinterest is mostly used by women. Is that the case?
It's not how we think about the site; we try to build things for the whole world. That said, most of our users right now are women. I think that's a function of how the site and the service tend to spread along interest categories. We'll see an area like interior decorating, and then an adjacent interest will open up. It's becoming more diverse. I would guess that when camping opens up as an interest, fishing would be an adjacency.

The site is established and popular. Are you still innovating?
All we really think about day to day is: how do we make Pinterest a better service for discovering things and taking action on them? When we build things, we start with what we want to enable the users to do, what we want to make better about the service. There are really hard technical problems, like how we recommend things; there are design problems, how we deliver all that on a three-and-a-half-inch screen; and there are social design problems, how we encourage people to help one another. They all have to be delivered to you in something that you can download and instantly say, "Oh yeah, I want to use this." It's a fun, messy process.

How do you plan to make money?
The whole reason Pinterest exists is to help people discover the things that they love and then go take action on them, and a lot of the things they take action on are tied to commercial intent. I had a kid recently, so I planned the kid's nursery with my wife on Pinterest. I plan activities to do with my kid. A lot of those things end up being the blueprint of what I end up buying and doing. I think that's at the heart of how we'll eventually make money. It would be better if it showed me the perfect crib to get and I could go get it—that would be better than Pinterest is now.

COURTESY OF PINTEREST



AN ENERGY BREAKTHROUGH

BY MARTIN LAMONICA PHOTOGRAPHS JARED LEEDS

A tiny startup called **Ambri** wants to transform our energy system with massive liquid-metal batteries.

Standing next to the Ping-Pong table in the offices of the battery startup Ambri, chief technology officer David Bradwell needs both hands to pick up what he hopes will be a building block for a new type of electricity grid. Made of thick steel, it's a container shaped like a large round cake pan, 16 inches in diameter. Inside it are two metal pucks and some salt powder; a round plate has been welded to the top to make a 100-pound battery cell.

By stringing together a number of these large cells, Ambri plans to make huge batteries, as big as 40-foot shipping containers. It's not only their size that makes them novel: the chemistry in Ambri's technology is different from any other currently used in batteries. When the cell is heated to around 500 °C, the disks and powder inside—the battery's electrodes and electrolyte, respectively—will melt. The result is a battery whose components are all liquid. Conventional rechargeable batteries have solid electrodes that degrade with use, but a battery with only liquid parts could last for years without losing much of its energy storage capacity. The molten materials can also operate at much higher current densities than solids, and for longer periods of time.

Ambri cofounder Donald Sadoway, a professor of materials chemistry at MIT, conceived of the liquid-metal cell as a way to build a grid battery that could store many hours' worth of energy from solar and wind power at very low cost. Because a stationary battery intended to store power for the grid wouldn't have to be lightweight like the batteries in our laptops, cars, and flashlights, he was free to depart dramatically from the chemistry that powers those devices. The result is a battery that's made from abundant, inexpensive materials in a simple production process. It can safely handle large currents and deliver power in quick bursts or for an extended period.

If Ambri or anyone else can make grid storage cheap and dependable, it will change the way we get electricity. Because the output of wind and solar farms is intermittent, these renewable sources alone can't reliably power the entire grid, or even most of it. Grid operators need to ensure a steady balance between the power being consumed and the amount being generated. The system must be able to meet peak demand, which typically occurs when people turn on their air conditioning on hot summer days. That means wind and solar farms are typically backed up with natural-gas plants that can quickly add to the electricity supply.

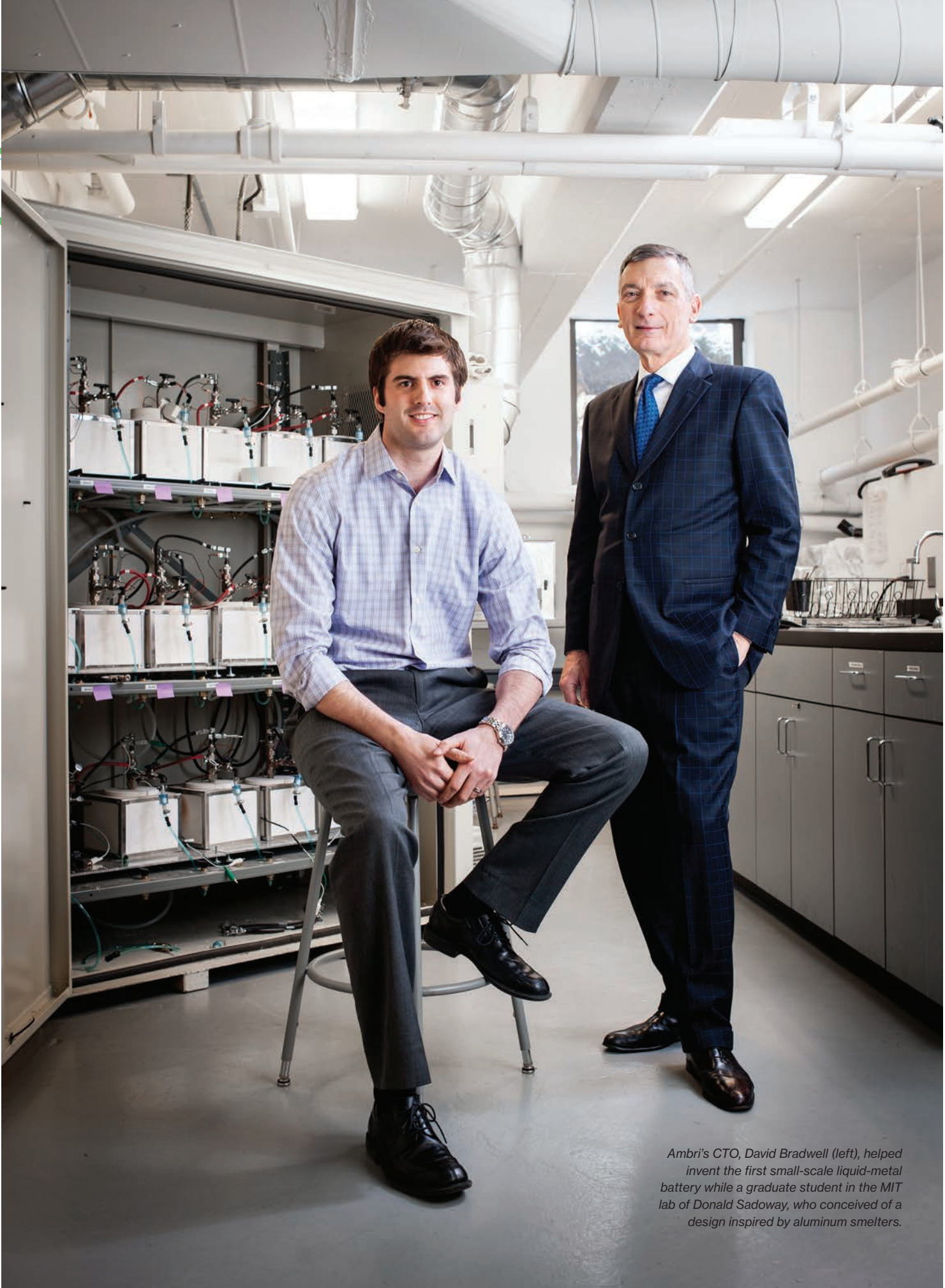
BIOMEDICINE 50 ▶

Diagnostics for All NEW
PRIVATE | FOUNDED: 2007
Making inexpensive diagnostic tests on paper, which could greatly benefit poor countries.

Foundation Medicine
PRIVATE | FOUNDED: 2010
Offering a genetic test that helps doctors select the right drugs for cancer patients.

Illumina NEW
PRIVATE | FOUNDED: 1998
Driving down the cost of DNA sequencing and creating new diagnostics markets for genomics.

Novartis
PUBLIC | FOUNDED: 1996
Developing a continuous drug-manufacturing process that could combine compounds quickly and in novel ways.



Ambri's CTO, David Bradwell (left), helped invent the first small-scale liquid-metal battery while a graduate student in the MIT lab of Donald Sadoway, who conceived of a design inspired by aluminum smelters.

The ability to bring in stored power when needed would mean that some of those fossil-fuel power plants could be closed and new ones wouldn't have to be built. But so far we have no good all-purpose way to store energy for the grid. Today, 99 percent of grid storage takes the form of "pumped hydro"—water is pumped uphill to a reservoir and released to turn a generator when energy is needed. This low-tech method is efficient, and it's cheap over the long term, but it's limited to places with mountains and readily available water. As a result, it provides less than 1 percent of the power capacity in the United States on a given day, according to Mark Johnson, director of the grid storage program at the Department of Energy's ARPA-E research agency.

Dozens of companies are developing new energy storage devices, including various types of giant batteries, large spinning cylinders called flywheels, and even compressed-air storage tanks. But so far none of these approaches are cheap enough to be competitive. Depending on its size, a pumped-hydro plant can deliver power for tens of hours at a cost of about $100 per kilowatt-hour. Grid-level batteries can cost 10 times that, which is why there are just a few hundred megawatts of battery power on the grid—less than the amount contributed by one full-size power plant.

Ambri is betting that by using cheap materials and a simple battery design with no moving parts, it can deliver reliable bulk energy storage for well below $500 per kilowatt-hour. That's still more expensive than pumped hydro, but since batteries can be placed nearly anywhere, Ambri thinks its technology can be the most economical choice for many applications.

"One metric matters more than anything else on the grid," says Johnson. "It's cost, cost, cost."

Shot Glasses

When Sadoway first considered grid storage in 2005, he looked to aluminum smelters for inspiration. These massive machines, which can stretch to more than 200,000 square feet, use huge amounts of electricity to extract aluminum from molten aluminum oxide through electrolysis. Sadoway, who is trained as a metallurgist, realized that smelting could provide a template for a rechargeable battery that tolerates the current levels needed for the grid. "I looked at that and said, Wow, that looks like half of a battery! And it's big, it's scalable, and it's cheap," he says.

After hitting upon the idea of the liquid-metal battery, Sadoway searched for the perfect electrodes: he ended up choosing magnesium and antimony because they are cheap and separate naturally when in liquid form, the lighter magnesium rising to the top. A liquid-salt electrolyte rests between the magnesium and antimony electrodes, creating a cell with three layers.

When the battery is called upon to deliver power to the grid, magnesium atoms from the top layer—the anode—give off electrons. The resulting magnesium ions travel through the electrolyte and react with the antimony, forming an alloy and expanding the bottom layer of the cell—the cathode. When the battery is charging, it acts like the smelter, liberating the magnesium from its alloy and sending it back through the electrolyte to rejoin the magnesium electrode. The intense flow of current generates the heat used to keep the metals in a molten state. (Ambri has switched to cheaper metal alloys and a salt mixture, but the chemistry works the same way.)

In 2007, when Bradwell was a student in Sadoway's lab, he used the magnesium-antimony technology to make an experimental battery with about the diameter of a shot glass. By 2009 it had attracted nearly $11 million in research funding from ARPA-E and the French oil company Total. The next year, Sadoway and Bradwell created a company called Liquid Metal Battery Corporation; they then secured seed funding from Bill Gates and Total.

The founders expected the technical work to take longer than the five to seven years that venture capitalists are typically willing to wait before cashing out, so at first they didn't take money from such investors as many other clean-tech startups had done. By the summer of 2011, though, it was time to build a product. Sadoway recruited a new CEO, Philip Giudice, who helped secure a $15 million round of investment led by Khosla Ventures. The company changed its name to Ambri—based on the name of Cambridge, where the technology was invented.

Energy Storage Trade-offs

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Pumped storage	High capacity, low cost	Special site requirements
Flow batteries	High capacity	Low energy density
Flywheels	High power	Low energy density

ELECTRICITY STORAGE ASSOCIATION

BIOMEDICINE

UniQure
NEW
PRIVATE | **FOUNDED:** 2012

Restoring the promise of gene therapy. The Dutch company has approval to treat a rare metabolic disorder.

TRANSPORTATION

Audi
NEW
PUBLIC | **FOUNDED:** 1909

Pushing autonomous cars closer to fruition with a laser-scanning road detector that fits in a vehicle's front grille.

SpaceX
PRIVATE | **FOUNDED:** 2002

Launching the private spaceflight business. Its rockets are making new space-based businesses possible.

Toyota
NEW
PUBLIC | **FOUNDED:** 1937

Expanding its dominance of the hybrid-car market with its new plug-in version of the Prius.

At least at first, Ambri wants to avoid working with electric utilities, says Giudice, a former Massachusetts state energy official: utilities are conservative and have little financial incentive or regulatory pressure to try out new technologies. Instead, it will initially target military bases and other facilities willing to pay for backup power, such as data centers. These applications are not a huge market, but they will help demonstrate and test the battery.

Later this year, the company plans to make a refrigerator-size module by stacking hundreds of hockey-puck-size cells and wiring them in series. By 2014, the researchers expect, 80 of those modules will be packed together in a full-scale commercial prototype that will generate 500 kilowatts and store two megawatt-hours—enough to power 70 U.S. homes for a full day.

Even after that prototype is up and running, Giudice says, Ambri still plans to avoid the complex, regulation-heavy world of utilities in favor of independent power producers, companies that develop and own energy projects. In west Texas, for example, there's often a surplus of wind energy at night, when demand and price are lowest. Battery storage would let a wind energy developer provide that power at peak times and earn more money. Another attractive early market is in cities where batteries could be more cost-effective than adding new power lines to meet peak demand for electricity, Giudice says.

If all goes as hoped, Ambri will be able to demonstrate its batteries in multiple installations and show utilities that the technology is low risk, Giudice says. At that point, the company can approach utilities and the state regulators that approve investments in grid equipment. A fully realized utility storage market could be worth billions of dollars in five to 10 years.

To make Ambri's battery cells, liquid-metal electrodes and a liquid-salt electrolyte are sealed in a steel container like this one.

The Money

Holding up one of the original shot-glass-size cells next to progressively larger ones—four inches, six inches, and the hefty 16-inch cell—Bradwell shows how far his team has come. But Ambri's researchers now face the challenge of scaling the liquid-metal battery up to industrial size. Among other tasks, they must design airtight seals on the cells and create a thermal management system that makes sure the heat given off by charging and discharging is enough to keep the components liquid. The group is still determining the individual size that will minimize the fabrication cost, but the cells will be square, between four and 16 inches per side, and about two inches tall.

Ambri has enough money to build its first prototypes. But scaling up production will require more capital at a time when the financing environment for clean-tech companies is far from auspicious. Spooked by poor returns, a series of well-publicized bankruptcies, and the expense of building manufacturing capacity, many venture capitalists have abandoned clean tech, leaving few financing options.

The financing hurdles are particularly high because grid storage startups are taking on big technical challenges in an industry that barely exists. "Venture capitalists like to take either technology or business risk. Some people can take both, but most don't," says Bilal Zuberi, an investor at General Catalyst Partners, who has invested in a startup developing grid storage technology based on compressed air. In its next round, Ambri intends to go after investors from the power industry, hoping that companies such as General Electric, ABB, and Siemens can provide not only money but also credibility and expertise in manufacturing and marketing. But even if Ambri's engineering is flawless and the company secures all the money it needs, it will face the same obstacle confronting so many other alternative energy companies: cheap natural gas. Since natural gas has become the preferred fuel for power generation in the United States, the price that any grid storage technology must meet to be competitive has fallen much lower.

The most significant factor in Ambri's favor may ultimately be the creaky state of the grid itself. The massive outages caused by Hurricanes Sandy and Irene painfully exposed how vulnerable the power system is, leading politicians and the public to demand solutions. Grid storage could add much-needed resilience and flexibility, providing backup power to buildings and even communities while allowing grid operators to smooth out fluctuations in power supply. Some of the large, centralized power plants that must now be maintained to make sure supply can meet demand would no longer be needed.

Realizing this vision of an electricity system buffered by hundreds of large batteries will take many years, and it will mean upending the status quo in the electric power industry. That's no easy task. But Ambri believes its battery offers a way to begin taking it on. T

Martin LaMonica is an MIT Technology Review *contributing editor.*

Intentionally engineering Earth's atmosphere to offset rising temperatures could be far more doable than you imagine, says David Keith. But is it a good idea?

A Cheap and Easy Plan to Stop Global Warming

By David Rotman

Here is the plan. Customize several Gulfstream business jets with military engines and with equipment to produce and disperse fine droplets of sulfuric acid. Fly the jets up around 20 kilometers—significantly higher than the cruising altitude for a commercial jetliner but still well within their range. At that altitude in the tropics, the aircraft are in the lower stratosphere. The planes spray the sulfuric acid, carefully controlling the rate of its release. The sulfur combines with water vapor to form sulfate aerosols, fine particles less than a micrometer in diameter. These get swept upward by natural wind patterns and are dispersed over the globe, including the poles. Once spread across the stratosphere, the aerosols will reflect about 1 percent of the sunlight hitting Earth back into space. Increasing what scientists call the planet's albedo, or reflective power, will partially offset the warming effects caused by rising levels of greenhouse gases.

The author of this so-called geoengineering scheme, David Keith, doesn't want to implement it anytime soon, if ever. Much more research is needed to determine whether injecting sulfur into the stratosphere would have dangerous consequences such as disrupting precipitation patterns or further eating away the ozone layer that protects us from damaging ultraviolet radiation. Even thornier, in some ways, are the ethical and governance issues that surround geoengineering—questions about who should be allowed to do what and when. Still, Keith, a professor

Illustrations by Grafilu

of applied physics at Harvard University and a leading expert on energy technology, has done enough analysis to suspect it could be a cheap and easy way to head off some of the worst effects of climate change.

According to Keith's calculations, if operations were begun in 2020, it would take 25,000 metric tons of sulfuric acid to cut global warming in half after one year. Once under way, the injection of sulfuric acid would proceed continuously. By 2040, 11 or so jets delivering roughly 250,000 metric tons of it each year, at an annual cost of $700 million, would be required to compensate for the increased warming caused by rising levels of carbon dioxide. By 2070, he estimates, the program would need to be injecting a bit more than a million tons per year using a fleet of a hundred aircraft.

One of the startling things about Keith's proposal is just how little sulfur would be required. A few grams of it in the stratosphere will offset the warming caused by a ton of carbon dioxide, according to his estimate. And even the amount that would be needed by 2070 is dwarfed by the roughly 50 million metric tons of sulfur emitted by the burning of fossil fuels every year. Most of that pollution stays in the lower atmosphere, and the sulfur molecules are washed out in a matter of days. In contrast, sulfate particles remain in the stratosphere for a few years, making them more effective at reflecting sunlight.

The idea of using sulfate aerosols to offset climate warming is not new. Crude versions of the concept have been around at least since a Russian climate scientist named Mikhail Budkyo proposed the idea in the mid-1970s, and more refined descriptions of how it might work have been discussed for decades. These days the idea of using sulfur particles to counteract warming—often known as solar radiation management, or SRM—is the subject of hundreds of papers in academic journals by scientists who use computer models to try to predict its consequences.

But Keith, who has published on geoengineering since the early 1990s, has emerged as a leading figure in the field because of his aggressive public advocacy for more research on the technology—and his willingness to talk unflinchingly about how it might work. Add to that his impeccable academic credentials—last year Harvard lured him away from the University of Calgary with a joint appointment in the school of engineering and the Kennedy School of Government—and Keith is one of the world's most influential voices on solar geoengineering. He is one of the few who have done detailed engineering studies and logistical calculations on just how SRM might be carried out. And if he and his collaborator James Anderson, a prominent atmospheric chemist at Harvard, gain public funding, they plan to conduct some of the first field experiments to assess the risks of the technique.

Leaning forward from the edge of his chair in a small, sparse Harvard office on an unusually warm day this winter, he explains his urgency. Whether or not greenhouse-gas emissions are cut sharply—and there is little evidence that such reductions are coming—"there is a realistic chance that [solar geoengineering] technologies could actually reduce climate risk significantly, and we would be negligent if we didn't look at that," he says. "I'm not saying it will work, and I'm not saying we should do it." But "it would be reckless not to begin serious research on it," he adds. "The sooner we find out whether it works or not, the better."

WHY IT MATTERS

The climate warming resulting from increased levels of carbon dioxide will last at least a thousand years. Geoengineering might be the only way to turn down Earth's thermostat.

The overriding reason why Keith and other scientists are exploring solar geoengineering is simple and well documented, though often overlooked: the warming caused by atmospheric carbon dioxide buildup is for all practical purposes irreversible, because the climate change is directly related to the total cumulative emissions. Even if we halt carbon dioxide emissions entirely, the elevated concentrations of the gas in the atmosphere will persist for decades. And according to recent studies, the warming itself will continue largely unabated for at least 1,000 years. If we find in, say, 2030 or 2040 that climate change has become intolerable, cutting emissions alone won't solve the problem.

"That's the key insight," says Keith. While he strongly supports cutting carbon dioxide emissions as rapidly as possible, he says that if the climate "dice" roll against us, that won't be enough: "The only thing that we think might actually help [reverse the warming] in our lifetime is in fact geoengineering."

The Experiment

David Keith clearly sees the world through the eyes of an experimental physicist. During his time as a graduate student in the MIT lab of David Pritchard, he spearheaded a project that built the first atom interferometer. Keith and his coworkers outcompeted some of the world's top atomic-physics labs, including one at Stanford led by Steven Chu, who later won a Nobel Prize and served as the U.S. secretary of energy. Everyone knew the interferometer would be a breakthrough, recalls Pritchard, but Keith displayed a rare combination of creativity and the ability to "blast ahead" through the frustrations and difficulties of building and testing it. Keith, however, says his remarkable achievement caused him to "walk away from [atomic] physics," in part because one of the most obvious

applications for atom interferometry was in highly accurate gyroscopes for submarines carrying ballistic missiles.

Soon, Keith had moved on from the esoteric world of atomic physics to energy problems. In 1992, he published a paper called "A Serious Look at Geoengineering," one of the first rigorous scientific reviews of the topic. Almost no one cared.

Indeed, the field of geoengineering remained more or less dormant for much of the next decade. A handful of serious scientists wrote occasional papers and the field attracted a robust fringe of fanatics, but academic discussion of the subject—let alone actual research—remained somewhat taboo. Many felt that discussing geoengineering as a realistic option would take attention away from the urgency of cutting greenhouse-gas emissions. Then, in 2006, Paul Crutzen, one of the world's leading climate scientists and a winner of the 1995 Nobel Prize in chemistry for his work on atmospheric ozone depletion, published a paper called "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?"

In the paper, Crutzen acknowledged that the "preferred way" to address climate warming was to lower emissions of greenhouse gases, but he concluded that making sufficient cuts was only "a pious wish." Not only did he give his blessing to the idea of geoengineering, but he singled out the use of sulfate aerosols in particular as worthy of research, even though it's well known that the particles can facilitate the chemical reactions that lead to ozone loss. He pointed to the eruption of Mount Pinatubo on an island in the Philippines in 1991 as evidence that sulfate particles can effectively cool the planet. The giant volcano spewed some 10 million metric tons of sulfur into the stratosphere. Subsequent analysis showed that the world's temperature decreased by an average of 0.5 °C for a couple of years.

At a time when many experts were increasingly frustrated with the lack of progress in cutting greenhouse gases, the paper permitted the topic of intentional climate alteration to be more openly discussed. In subsequent years, geoengineering gained still more attention, including high-profile reviews by the U.K.'s Royal Society and the Washington-based Bipartisan Policy Center, both of which recommended further exploring SRM. (Keith helped write both reports.) Endless modeling and computer simulations have followed. But now Keith is anxious to conduct field experiments.

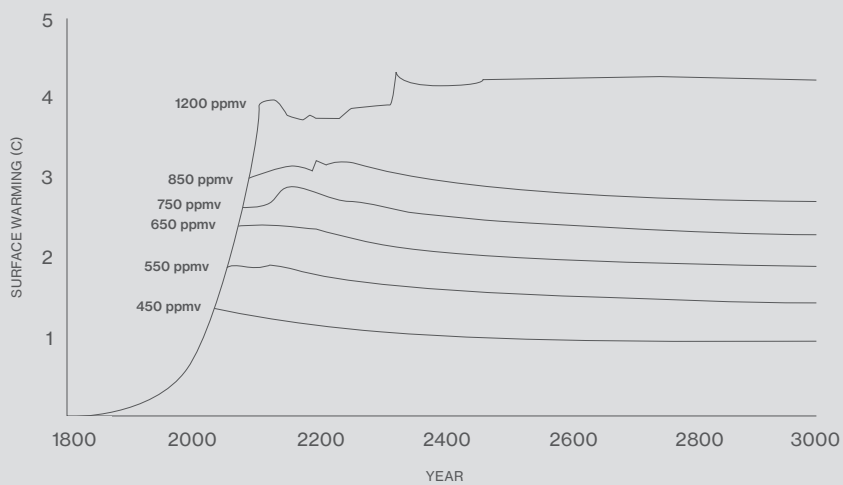
That idea is highly controversial. Many climate scientists still consider field experimentation premature, and critics of geoengineering tend to believe it would be the first step in what would turn into an inexorable move toward full-scale deployment. Last year, a public outcry led by several international environmental groups helped shut down a simple experiment that a team of British researchers had proposed. The group wanted to pump water to a height of one kilometer through a thin hose held aloft by a helium balloon. The object would have been to test whether a similar system could someday be used to inject sulfur particles into the stratosphere at an altitude of 20 kilometers.

The experiments Keith and Anderson are considering would be far more ambitious. Their goals: first, to test how sulfuric acid should be distributed to optimize the size and longevity of the resulting particles, and second, to measure how sulfur affects ozone at the altitude and under the conditions associated with SRM.

Anderson, who helped unravel the chemistry behind the ozone hole that appeared in the Antarctic during the 1980s, says the "demonic system" that implicates sulfate particles in ozone destruction is highly sensitive to the levels of water vapor in the air. So in one set of experiments, using a scheme based on Anderson's earlier work, the group would

EARTH'S THERMOSTAT

Even if carbon dioxide emissions are stopped at various atmospheric levels (in parts per million by volume, or ppmv), elevated temperatures will continue largely unabated for many centuries.*



Based on one estimate of climate sensitivity

send a helium-filled balloon to the lower stratosphere, use a Kevlar thread to lower canisters filled with water vapor and sulfur, and release small amounts of the test samples. Then the researchers would drop down miniature laser-based analytic instruments to monitor the chemistry in the small "seeded" area. The setup, says Anderson, provides "exquisite control" and a way to precisely monitor the effect of different amounts of sulfur and water vapor.

Anderson stresses that the experiment would have no conceivable impact on the stratosphere: it would use only "microamounts" of sulfur and would be confined to a very small region. And he says it is critical to study the reactions under the conditions "where they actually take place" and not in the confines of the lab.

Still, while he is keen to test SRM, Anderson says that adding sulfates to the stratosphere worries him "tremendously" because of the potential impact on ozone. He points to a study his group published last year in *Science* showing that increasingly intense summer storms over the United States—triggered by climate warming—are injecting more water vapor into the stratosphere. That, he says, could speed the ozone-destroying reactions: "If nature is adding increased water vapor to the stratosphere and we're adding sulfates, it is a very lethal cocktail for ozone loss."

Keith appears more sanguine. "The uncertainties are substantial," he says. "You could get very bad [ozone] outcomes, but there are also ways where you could have no impact, or even a positive impact, on ozone." In any case, he says, it is "just crazy" not to begin conducting experiments on solar geoengineering to find out. Nearly all the work done on SRM is based on computer modeling, and Keith says we need to move to "perturbation experiments" to learn whether we can use it to safely and effectively intervene in the climate. The field "really needs to grow up" and begin experiments in "the real world," he says.

Barking Mad

Critics of SRM—and even its advocates—note that the technology has numerous limitations, and that no one is entirely sure what the consequences would be. Sulfate aerosols reflect sunlight in the upper atmosphere, thus directly cooling the planet. But greenhouse gases operate very differently, trapping long-wave infrared radiation escaping from Earth's surface and thus warming it. While sulfates would be likely to offset warming, it's not clear exactly how they would counteract some of the other effects of greenhouse gases, particularly changes in precipitation patterns.

While sulfates would be likely to offset warming, it's not clear how they would affect precipitation.

And SRM would do nothing to reduce the acidification of the oceans caused by rising levels of carbon dioxide in the atmosphere.

"The term 'solar radiation management' is positively Orwellian," says Raymond Pierrehumbert, a geophysicist at the University of Chicago. "It's meant to give you a feeling that we really understand what we would be doing. It's a way to increase comfort levels with this crazy idea. What we're really talking about is hacking the planet in a case where we don't really know what it is going to do." In delivering the prestigious Tyndall Lecture at the annual American Geophysical Union meeting last December, he said the idea of putting sulfate aerosols in the stratosphere was "barking mad."

Pierrehumbert also rejects the value of doing field experiments. "The whole idea of geoengineering is so crazy and would lead to such bad consequences, it really is pretty pointless," he says. "We already know enough about sulfate albedo engineering to know it would put the world in a really precarious state. Field experiments are really a dangerous step on the way to deployment, and I have a lot of doubts what would actually be learned."

The fundamental problem with albedo engineering, says Pierrehumbert, is that once we start using it, we'll need to continue indefinitely. Since it only offsets warming, once the process stops, temperature changes caused by greenhouse gases will manifest themselves suddenly and dramatically. "If you stop—or if you *have* to stop—then you're toast," he says. Even using it as a temporary Band-Aid doesn't make sense, he argues: "Once you get to the point in terms of climate changes that you feel you have to use it, then you have to use [SRM] forever." He believes that this makes the idea a "complete nonstarter."

Besides, Pierrehumbert says, our climate models "are nowhere near advanced enough for us to begin thinking of actually engineering the planet." In particular, computer models don't accurately predict specific regional precipitation patterns. And, he says, it's not possible to use existing models to know how geoengineering might affect, say, India's monsoons or precipitation in such drought-prone areas as northern Africa. "Our ability to actually say what the regional climate patterns will be in a geoengineered world is very limited," he says.

Alan Robock, meanwhile, has a long list of questions concerning SRM, at the top of which is: can it even be done? Robock, an expert on how volcanoes affect climate and a professor of environmental sciences at Rutgers University, cautions that while the Pinatubo eruption confirmed the cooling effect of sulfate aerosols, it injected a massive amount of sulfur dioxide into the stratosphere over a few days. Solar geoengineering would use far less sulfur but disperse it continuously over an extended

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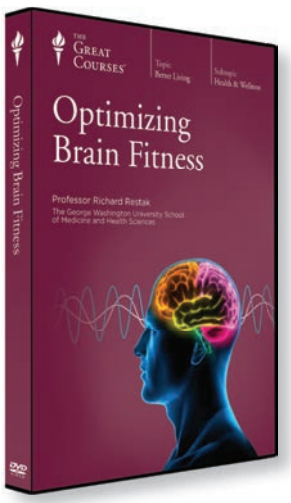

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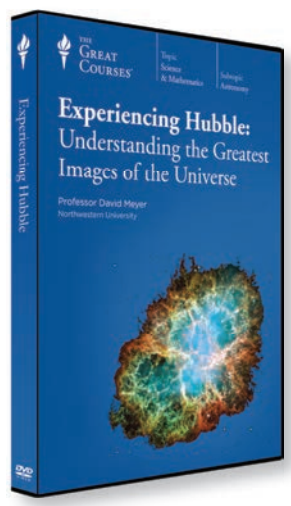

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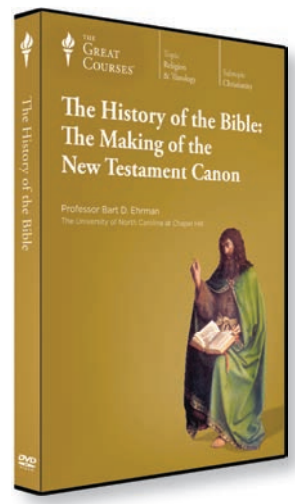

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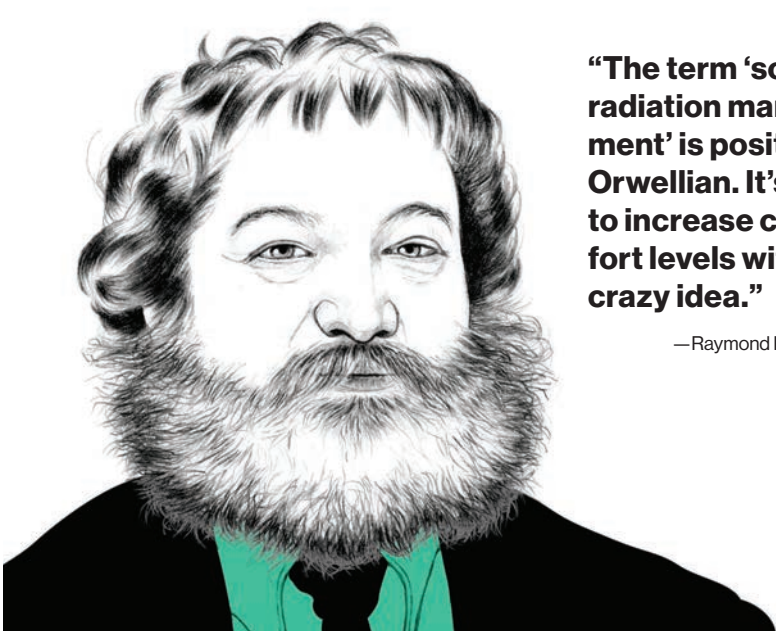
period. That could be a critical difference. The optimal way to achieve SRM is with sulfur particles only about half a micrometer in diameter. Sunlight reflects off the surface of the particles, and smaller particles have more surface area than larger ones, making them far more efficient at blocking the sun. Robock worries that as sulfur is continuously injected and concentrations build up, the small particles will clump together into large ones, necessitating far more sulfur than some current proposals assume.

These details of aerosol chemistry could help determine the viability of SRM. "David [Keith] thinks it is going to be easy and cheap, and I don't agree," says Robock. He estimates that several million tons of sulfur would have to be injected into the atmosphere annually to offset doubled levels of carbon dioxide, but if the particles clump together, "it could be many times that."

Research so far shows that producing a cloud in the stratosphere—Robock's preferred description of SRM—"could cool the climate," he says. "But you would have a very different planet, and other things could be worse." He points out, for example, that in the aftermath of Mount Pinatubo, rainfall decreased significantly in some parts of the world. Robock supports more modeling on solar geoengineering, but "right now, I don't see a path in which it would be used," he says. "I don't see how the benefits outweigh the negatives."

Still, climate scientists differ widely in the way they interpret the research on those risks. Phil Rasch, for one, who is chief scientist for climate science at the Pacific Northwest Laboratory in Richland, Washington, cautiously says the models do not yet indicate "showstoppers" that would preclude consideration of certain SRM strategies.

Rasch, who published a paper with Crutzen in 2008 on using sulfate aerosols for geoengineering, says research shows that the particles will cause some ozone depletion—"it is absolutely something we need to pay attention to"—but that the loss of ozone is somewhat tempered by the ability of the sulfate particles to block ultraviolet radiation. As for rainfall, he says, models tend to agree that SRM "leads to a [future] world that's closer to the present day with respect to precipitation than if you don't geoengineer." Overall, says Rasch, SRM would stave off some effects of climate change, though "some parts of the planet are more strongly affected than others, and there are many issues that remain unexplored."



"The term 'solar radiation management' is positively Orwellian. It's a way to increase comfort levels with this crazy idea."

—Raymond Pierrehumbert

A Moratorium

The scientific uncertainties and the prospect of winners and losers among different parts of the world make it almost unfathomably difficult to envision how SRM might be appropriately implemented and controlled. How could we fashion the international system of governance that would eventually be needed? Who would decide how and when to implement the technology? Who would monitor and control it? Who would set Earth's thermostat and at what temperature? If anything, the questions about who would make the decisions on solar geoengineering are more daunting than the questions about the science itself.

While the need for international governance is still years in the future, Keith and several close collaborators, including Edward Parson, a law professor at the University of California, Los Angeles, are already thinking about how such a system might evolve. Research on the technology is key, Parson says, to achieving a better understanding of what solar geoengineering can do and what the risks are. Without such knowledge, he says, "you don't know what you need to govern."

The controversy over field experiments, such as the ones Keith and Anderson are designing, is emerging as an early battleground for the social and political issues. Keith is adamant that work will not go forward unless he and his colleagues receive public funding and approval from established scientific agencies. Indeed, he and his collaborators see the experiments as an

early test not only for the technology but also for how a governance system can work. The hope, says Parson, is that the funding and approval process could provide an opportunity to establish "norms" that will help shape longer-term discussions—standards such as transparency, public review, and open disclosure of the results.

No one thinks that field experiments involving tiny amounts of sulfur would be physically dangerous, says Parson. "What concerns people," he says, "is the political and social consequences of the research going ahead, followed by bigger and bigger experiments—and then you're on the slippery slope all the way to full-scale deployment." These worries should be taken seriously, he says: "You need to encourage small-scale research, but you need some kind of limited governance to mitigate the risk of a slide to deployment." Established scientific funding agencies could probably take care of that, he believes. And he suggests that early experiments must be strictly limited, and researchers need to clearly state that no one is going to do anything big for the time being.

Keith and his collaborators are pushing fellow researchers to sign an agreement that would "function like a moratorium" on deploying solar engineering. That, Keith believes, could calm fears that some are rushing ahead on the technology—worries that he concedes are "not ungrounded," since there are, in fact, no international laws or regulations barring anyone from implementing geoengineering schemes. By signing a moratorium, he hopes, scientists could "help free up research" on the risks and efficacy of SRM.

Switching It On

For very brief spells, Keith sometimes lapses into animated annoyance with SRM critics. A moment later, however, he is calmly and logically countering the criticism with responses he has developed after years of thinking and writing about geoengineering. He sketches a graph showing that, in fact, sulfur injection could be rationally ended a century or less after it's begun; while the underlying climate changes it was masking would return, the rate of change affecting ecosystems and humans would have been slowed and managed. The idea that initiating SRM would commit us to continuing it indefinitely "is just not true," he states with characteristic self-confidence.

Even many of the strongest advocates of SRM research say the technology would be a nearly unthinkable last resort for a desperate world facing climate changes so destructive that the risks would be worth taking. Keith, however, has a far less apocalyptic vision. "If we've actually found something that could substantially reduce the risk of climate change over the next century and save a lot of lives, that's nothing to be upset about," he says. "It's something to celebrate." In fact, he says framing the case for geoengineering as a last resort in a climate emergency is "a bit of a rhetorical trick": it leaves undefined what a "climate emergency" is, and "there is no simple definition."

It would be an extreme action, creating a different planet—even the color of the sky would be whiter.

The approach Keith proposes is at once more deliberate and far more radical: "In my view, we should begin real research now, and if it bears out that [SRM] could meaningfully reduce climate risks without too many risks of its own—which may or may not turn out to be true—then we should actually begin doing this relatively soon, but with a very slow ramp." He believes the technology could be ready to be deployed as early as 2020 (or, more realistically, 2030) and would involve levels of stratospheric sulfur "practically" within normal ranges for the first decade. The process could be monitored and evaluated, and because the amounts of sulfur injected into the stratosphere would be relatively small, "the chances of a big problem are pretty close to zero."

It is often assumed that SRM would be "turned on with a big switch," says Keith. "But there's no reason you can't ramp it up." And that ability to turn on the system slowly and with minimal risk is behind his "willingness to take geoengineering seriously," he says: "If it was a one-time decision, I would be much more skeptical about doing it. It would be very hard to persuade me that it was sensible." Given the possibility of a more deliberate approach, "I lean pretty strongly, I got to say, to doing it."

Listening to Keith's logical arguments and careful descriptions of how SRM might be carried out, it's just possible to start believing that intentionally adjusting the climate wouldn't be an extreme action. But it would. It would create a different planet—even the color of the sky would be whiter. And it would almost certainly be driven by desperation.

On the other hand, the buildup of greenhouse gases is already altering the atmosphere and climate in an unprecedented and uncontrolled manner. How big a leap is it to intentionally "engineer" ways to begin counteracting that? And Keith is surely right that climate researchers should explore solar geoengineering to determine whether it would actually work and how safe it would be, and that political scientists need to start thinking about how we might implement such an unprecedented planetary project. All that will be left then is for society and governments to face the impossibly difficult task of deciding whether to do it.

David Rotman is editor of MIT Technology Review.

FREE SPEECH

— IN THE ERA OF ITS —

TECHNOLOGICAL AMPLIFICATION

A LETTER TO JOHN STUART MILL

BY

JASON PONTIN

MIT TECHNOLOGY REVIEW
VOL. 116 | NO. 2

GREETINGS, PALE GHOST. I DON'T KNOW WHAT NEWS REACHES YOU IN THE AFTERLIFE—WHETHER THERE IS A GOSSIPY DAILY BULLETIN, *THE HEAVENLY GAZETTE*, FILLED WITH OUR DOINGS; OR IF NEW ARRIVALS BRING STORIES OF DEVELOPMENTS ON EARTH; OR IF YOU STILL CARE ABOUT US AT ALL—BUT MUCH HAS CHANGED SINCE YOU DIED IN 1873. SOME OF THOSE CHANGES WOULD GRATIFY YOUR LIBERAL SPIRIT; STILL OTHERS, VEX. A FEW WOULD BAFFLE.

Adult suffrage is universal in democratic countries: women, for whose rights you campaigned so assiduously, may vote in Great Britain, the United States, Europe, Latin America, and much of Asia, including India. (The last should especially please the former chief examiner of correspondence at India House.) On the other hand, socialism enjoyed only a fleeting historical success in a few countries, because it contradicted the liberal principles you championed. No one solved what in your *Autobiography* you called "the social problem of the future": "how to unite the greatest liberty of individual action, with a common ownership of the raw material of the globe, with an equal participation of all in the benefits of combined labour."

The most sweeping changes have been technological. Less than one hundred years after you died, engineers constructed an "Electronic Numerical Integrator and Computer," heir to the "analytical engine" that your contemporary Charles Babbage planned but could not build, which could be programmed for general purposes, as Ada Lovelace had hoped. Billions of these so-called computers now exist—in homes, on desks, in walls, embedded into the very stuff of life—and they are connected in a planetary network, called the Internet, similar to the telegraph. We use them to communicate, write, and calculate, and to consult an immaterial library housing most of humanity's knowledge. It's hard to describe.

I'm sorry to say that the history of your own reputation has been mixed. For decades, your *System of Logic* (1843) and *Principles of Political Economy* (1848) were the standard texts. As late as the 1980s, when I was up at Oxford, they were still assigned. However, both fields have been formalized in ways you could not anticipate, and your books have been utterly superseded. But your lucid little book *On Liberty* (1859) has endured, as you predicted: "The *Liberty* is likely to survive longer than anything else that I have written, because … it [is] a kind of philosophic text-book of a single truth."

That truth, now so famous that it is simply called "Mill's harm principle," is worth quoting in full. I have in front of me the broken paperback copy of *On Liberty* that I first read at boarding school.

> The sole end for which mankind are warranted, individually or collectively, in interfering with the liberty of action of any of their number is self-protection … The only purpose for which power can be rightfully exercised over any member of a civilized community, against his will, is to prevent harm to others. His own good, either physical or moral, is not a sufficient warrant. He cannot rightfully be compelled to do or forbear because it will be better for him to do so, because it will make him happier, because, in the opinions of others, to do would be wise or even right … Over himself, over his own body and mind, the individual is sovereign.

Your harm principle has ever since guided open societies in the regulation of what may be said, written, or shown—what is commonly called freedom of speech, the subject of my letter to you. For although the First Amendment to the U.S. Constitution commands that "Congress shall make no law … abridging the freedom of speech, or of the press," and the U.N.'s Universal Dec-

laration of Human Rights (1948) states, "Everyone has the right to freedom of expression," all thoughtful people know that the freedom is qualified. Free speech is a contingent right that butts up against other rights and mores, some explicitly protected by laws, others implicitly understood, still others not yet established but possessing their advocates. Yet while this has been long recognized, the arduous business of explicitly defining the limits of what may be expressed is a relatively recent activity, and it owes everything to *On Liberty*. In the United States, since the Supreme Court decided *Shenck v. United States* (1919), the government has had to prove that any speech it seeks to limit would present a "clear and present danger." (Oliver Wendell Holmes, writing the unanimous opinion, gave the famous example of a person falsely shouting "Fire!" in a crowded theater.) Subsequently, the court has elaborated that test to protect advocacy of illegal action up to the point where a serious and imminent crime is "likely" to occur. (The 1969 ruling in *Brandenburg v. Ohio* allowed Clarence Brandenburg, a Ku Klux Klan leader, to call at a rally for "revengeance" against "niggers" and "Jews" but not, by implication, to instruct his followers to lynch Mr. Washington at 33 Linden Street.) The court has defended defamatory speech, "fighting words," and indecency. Not only in America, but in all nations committed to protecting the right, the standard for freedom of speech has become *presumptively* absolutist. Everyone presumes they may say what they like without penalty, unless censors can show that questionable speech would irremediably and immediately harm someone else.

FREE SPEECH IS NOT ACCEPTED AS A UNIVERSAL RIGHT. CHINA BANS ANYTHING SUBVERSIVE OF THE COMMUNIST PARTY'S RULE.

Your principle, in the jargon of engineers, "scaled" as new technologies and historical circumstances appeared and the globe became crowded with new people. Critics had noted that you never clearly defined "harm" but seemed to mean physical harm. That was clearly insufficient to practical purposes, and "harm" was everywhere expanded to include commercial damage, which is why copyright law sharply circumscribes what may be quoted or sampled without permission of the author or publisher. But your single truth has held. That is, until now.

THE SUNNY COMPROMISE

Three recent events call into question whether your principle will continue to scale in the future. Some of the terms and concepts I use will be unfamiliar. I understand Steve and Aaron have joined you in the fields of gold. Ask them to explain.

The companies that own the most popular sites on the Internet are incorporated in the United States, which enjoys the most expansive protections for free speech as well as the narrowest limits. Legally bound by the limits but not by the protections of the First Amendment and its case law, they have nevertheless followed the American standard in the terms of service they impose on their users. They have encouraged free speech where it is consistent with their businesses, and limited expressions illegal in the United States, such as lewd photographs of a child, which are evidence of a crime. More, the companies were founded in California's Silicon Valley, whose political culture can seem perplexingly libertarian even to other Americans. (The chief executive of one, Twitter, has called his company "the free speech wing of the free speech party.") But as the technologies created by these companies have come to touch nearly everyone who lives, their peculiar understanding of free speech has collided with different notions of what forms of expression are legal or proper.

The problem is that "harm" has been variously understood; there is no common definition. Democratic nations not part of what used to be called the Anglo-Saxon tradition have interpreted the word more broadly than Great Britain, the United States, Canada, Australia, or New Zealand. Because of two great wars and the murder of six million Jews by the German state, much of Europe outlaws political speech associated with revanchist nationalist parties, as well as expressions of hatred for the Jewish people. In Scandinavia, many kinds of hate speech are illegal because they are thought harmful to individual dignity. Even in the Anglophone countries, a narrow definition of harm emphasizing physical or commercial damage is not universally accepted: since the 1970s, some feminists have argued that pornography is a kind of violence against women. Further, free speech is by no means accepted as a universal right. China, the last great tyranny on Earth, absolutely bans anything subversive of the Communist Party's rule. Thai law will not permit criticism of the king. Wherever Sharia law is the foundation of a nation's legal code (and also in many countries, like India, where there is a very large Muslim population), depictions of the Prophet Muhammad are illegal, because Muslims believe such representation is blasphemous.

To all these, American Internet companies have proposed a sunny compromise. To governments whose understanding of free speech departs from the American standard, they have promised: we will comply with local laws. To communities convinced that hateful expression *is* harmful, they've said: we will censor hate speech. The compromise is a hack designed by Silicon Valley's engineers and lawyers to allow different legal and cultural conceptions of what may be expressed to coexist on sites used all over the world. But it has been a fidgety hack, requiring awkward accommodations.

In July of 2012, "Sam Bacile," later identified by the U.S. government as a Coptic Egyptian named Nakoula Basseley Nakoula, uploaded to YouTube two short videos, "The Real Life of Muhammad" and "Muhammad Movie Trailer." The videos were in English and purported to be trailers for a full-length movie, which has never been released; both depicted the Prophet Muhammad as a womanizer, a homosexual, and a child abuser. As examples of the filmmaker's art they were clownish. Nakoula, their producer, wished to provoke, but the videos languished on YouTube unseen and might never have been noticed had not Egyptian television, in September, aired a two-minute excerpt dubbed into Arabic. Enterprising souls provided Arabic captions for the videos, soon collectively named *The Innocence of Muslims*; millions watched them. In reaction, some Muslims rioted in cities all over the world.

The videos placed Google, which owns YouTube, in a difficult position. The company boasts of an official "bias in favor of free expression." Ross LaJeunesse, its global head of free expression and international relations, says, "We value free speech because we think it's the right thing to do for our users, and for society at large. We think it's the right thing for the Internet, and we think it's the right thing to do for our business. More speech and more information lead to more choices and better decisions for our users."

The U.S. government asked Google to review the videos in order to determine whether they violated the company's terms of service. A decision doubtless seemed urgent. In September, protesters breached the walls of the U.S. embassy in Cairo and replaced the Stars and Stripes with the black banner of militant Islam. Later that month, an American consulate in Benghazi, Libya, was attacked, and the U.S. ambassador and three other Americans were killed (an event thought at the time to be connected with the videos). By December, 600 people had been injured in demonstrations; 50 to 75 were dead. A consistent demand of the rioters, who mostly lived in countries without free speech and where the government licensed or directly owned the media, was that "America" should remove the videos from YouTube.

What was Google to do? As LaJeunesse explains, the company worries about requests to censor anything; after all, its mission is "to organize all the world's information." In general, the company complies with local laws, blocking search results or content illegal within a country, except when laws are so at odds with its corporate principles that senior management feels it cannot operate there. (Such was the case in China, from which Google retreated in March 2010; today the company has a research division inside the country, but search requests are rerouted to Google.com.hk in Hong Kong.) Specific requests to remove information are treated differently depending on whether they affect Google's search business, its advertising networks, or its platforms, YouTube and Blogger. When a search result is suppressed, Google shows users that the result has been removed. Advertising on Google's ad networks, AdWords and AdSense, must adhere to the company's guidelines. Material posted by third parties to YouTube or Blogger must conform to the platforms' terms of service. (For instance, YouTube's Community Guidelines prohibit sexually explicit images, hate speech, and "bad stuff like animal abuse, drug abuse, under-age drinking and smoking, or bomb making.") So much is posted to YouTube and Blogger that the company accepts only limited "intermediary liability," looking to its community to flag material that violates guidelines. Google is high-mindedly transparent about all requests to remove information: the company publishes a "Transparency Report" that describes requests from copyright owners and governments to remove information from its services (as well as requests from governments and courts to hand over user data).

AMERICAN INTERNET COMPANIES HAVE PROPOSED A SUNNY COMPROMISE, A HACK DESIGNED BY SILICON VALLEY'S ENGINEERS.

Google rejected the U.S. government's request to suppress *The Innocence of Muslims*, because the videos didn't violate YouTube's terms of service. (Although YouTube's prohibition on hate speech does include any expressions that demean a group "based … on religion," Google decided that the videos criticized the texts, stories, and prophets of Islam but not Muslims themselves—a nice distinction to the millions of Muslims who felt insulted.) The company did block the videos in Saudi Arabia, India, and Indonesia, where the

material was illegal. Other Muslim countries just blocked YouTube altogether. But in the middle of September, Google chose to temporarily restrict access to the videos in Egypt and Libya, because it worried about the "very sensitive situation in those countries." For slightly less than three weeks, Egyptians and Libyans could not watch *The Innocence of Muslims*. It was an unprecedented decision: Google had effectively announced that if protesters objected to something with sufficient violence, it would suppress legal speech that was consistent with its community guidelines.

The second event ensnared Twitter in Europe's idiosyncratic conceptions of free speech. The company has tried to conform to the sunny compromise. In January of 2012, it announced something called "country-withheld content": it would suppress tweets within a country in response to "a valid and properly scoped request from an authorized entity." Twitter hopes to be as transparent as Google, too: users must know a tweet has been censored. The first application of the policy was the blocking of Besseres Hannover, an outlawed anti-Semitic and xenophobic organization, in response to a request by the legislature of Lower Saxony. Beginning last October, German followers of Besseres Hannover were shown a grayed-out box with the words "@hannoverticker withheld" and "This account has been withheld in: Germany." The company's lawyer, Alex MacGillivray (@amac), tweeted: "Never want to withhold content; good to be able to do it narrowly and transparently."

No one felt much outrage when an obscure Hannoverian neo-Nazi group was put down. But Twitter's next use of country-withheld content was more troubling, because it was more broadly applied. Not long after the company blocked Besseres Hannover, in response to complaints from the Union of French Jewish Students, it chose to censor tweets within France that used the hashtag "#UnBonJuif" (which means "a good Jew"). French tweeters had been using the hashtag as the occasion for a variety of anti-Semitic gags and protests against Israel. (Samples: "A good Jew is a pile of ash" and "A good Jew is a non-Zionist Jew.") The tweets were not obscure: when it was taken down, #UnBonJuif was the third-most-popular trending term in France. But expressions of anti-Semitism are actual crimes in the Fifth Republic. The student union therefore asked Twitter to reveal information that could be used to identify the offending tweeters; the company declined, and the union took the case to civil court. In January, the Tribunal de Grande Instance ruled that Twitter must divulge the names of French anti-Semitic tweeters so that they could be prosecuted. The court also ruled that the company should create some mechanism to let its users flag "illegal content, especially that which falls within the scope of the apology of crimes against humanity and incitement to racial hatred" (as already exists on YouTube, for instance). As I write to you, Twitter has two weeks to respond. If the company neither hands over its users' information nor withdraws from France (neither very likely), then it is unable to apply the sunny compromise consistently. Instead, Twitter will comply with the local laws it finds convenient.

The third event upset observers who value privacy, respect women, and worry about sexual predation. Reddit, an online bulletin board whose links and material are generated by its community of users, hosts forums called "subreddits"; until recently, a number were dedicated to sharing photographs of pubescent and teenage girls. These subreddits were part of a larger trend of websites catering to a taste for images of young women who never consented to public exposure (examples include "self-shots," where nude photos intended to titillate boyfriends find their way online, and "revenge porn," sexually explicit photos of women uploaded to the Internet by bitter ex-boyfriends). The two most popular subreddits publishing images of young women, "r/jailbait" and "r/creepshot," didn't traffic in illegal child pornography; the forums' moderator, an Internet troll known as Violentacrez, was much valued by Reddit's registered users, called "redditors," for his industriousness in removing unlawful content. (I speak from hearsay; I never visited r/jailbait and r/creepshot.) Instead, the photographs of underage girls showed them clothed or partially clothed, and they were taken in public (where American courts have decided no one has a reasonable expectation of privacy). Inevitably, r/jailbait and r/creepshot attracted wide opprobrium (little wonder: a popular shot was the "upskirt"), and Adrien Chen, a writer at Gawker, identified (or "doxxed") Violentacrez as Michael Brutsch, a 49-year-old Texan computer programmer. Brutsch promptly lost his job and was humiliated.

GOOGLE SHOWED THAT IF PROTESTERS OBJECTED TO SOMETHING WITH SUFFICIENT VIOLENCE, IT WOULD SUPPRESS LEGAL SPEECH.

The redditors were unhappy, arguing that doxxing Violentacrez violated his privacy and betrayed the principles of free speech to which Reddit was committed. The moderators of r/politics fulminated, without apparent irony: "We feel that this type of behavior is completely intolerable. We volunteer our time on Reddit to

make it a better place for the users, and should not be harassed and threatened for that. Reddit prides itself on having a subreddit for everything, and no matter how much anyone may disapprove of what another user subscribes to, that is never a reason to threaten them."

In retaliation for Chen's article, the moderators of r/politics deactivated all links to Gawker, a sort of censorship of Gawker within Reddit's borders. Yishan Wong, the chief executive of Reddit, mildly noted that the delinking "was not making Reddit look so good," but he insisted in a memo to his users, "We stand for free speech. This means we are not going to ban distasteful subreddits." Then Reddit banned r/jailbait and similar forums, without revising the site's rules.

Silicon Valley's presumptively absolutist standard of free speech, based on a narrow definition of harm, was exported to parts of the world that did not comprehend the standard or else did not want it. In all three cases I describe, the sunny compromise was considered by the parties involved and, under challenge, collapsed.

FREE SPEECH MATTERS

John Stuart Mill, the Internet itself has a bias in favor of free expression. More, its technologies amplify free speech, widely distributing ideas and attitudes that would otherwise go unheard and cloaking speakers in pseudonymity or anonymity. In order to seem harmless, American Internet companies will fiddle with the sunny compromise, but it is an unsatisfactory hack. The Internet's amplification of free speech will be resented by those who don't like free speech, or whose motto is "Free speech for me but not for thee." It will all be very messy, and sometimes violent. All over the world people hate free speech, because it is a counterintuitive good.

Who hates free speech? The powerful and the powerless: ruling parties and established religions, those who would suppress what is said in order to retain power, and those who would change what is said in order to alter the relations of power. Who else? Those who do not wish to be disturbed also hate free speech. Why, they might say, should *I* care about free speech? *I* have nothing to say; and insofar as things should be said at all, I only want to hear the things that people like me say. Why should I have to hear things that are offensive, immoral, or even mildly irritating?

In the *Liberty* you provided answers to those who hate free speech. Your main explanation was bracingly utilitarian, as befitted the son of James Mill. We value free speech, you wrote, because human beings are fallible and forgetful. Our ideas must be tested by argument: wrong opinion must be exposed and truth forced to defend itself, lest it "be held as a dead dogma, not a living truth." (Your consequentialist followers said a flourishing marketplace of ideas was a precondition of participatory democracy and even of an innovative economy.) But after your youthful crisis of faith, when you rejected your father's system of thought, you were never a crabbed utilitarian: in your maturity, you always described utility broadly as that which tended to promote happiness, and you defined happiness so that it included intellectual and emotional pleasures. You believed we must be free to "[pursue] our own good in our own way, so long as we do not attempt to deprive others of theirs or impede their efforts to obtain it." Freedom of expression is both useful and moral, and the consequentialist and deontological justifications of free speech "climb the same mountain from different sides."

Because free speech is so important, and because the Internet will continue to amplify its expressions, U.S. Internet companies should apply a consistent standard everywhere in deciding what they will censor upon request. (Their terms of service are their own business, so long as they are enforced fairly.) The only principle I can imagine working is yours, where "harm" is interpreted to mean physical or commercial injury but excludes personal, religious, or ideological offense. The companies should obey American laws about what expressions are legal, complying with local laws only when they are consistent with your principle, or else refuse to operate inside a country. In the final analysis, humans, prone to outraged rectitude, need the most free speech they can bear.

U.S. INTERNET COMPANIES MUST APPLY A CONSISTENT STANDARD IN DECIDING WHAT THEY WILL CENSOR UPON REQUEST.

Heaven, I know, governs our affairs without a chief executive but with rotating committees of souls. (Vladimir Nabokov and Richard Feynman cochair the Committee on Light and Matter, where Nabokov oversees a Subcommittee on the Motion of the Shadow of Leaves on Sidewalks.) You argue all the time. Down here, we must follow your example although our circumstances are different. We have a right to say whatever we wish so long as we do not harm others, but we cannot compel others to listen, or expect never to be offended. T

Jason Pontin is editor in chief of MIT Technology Review.

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A BUSINESS REPORT ON

The Next Wave of Manufacturing

Is America ready for a manufacturing renaissance? Rising wages in China and cheap domestic energy won't be enough. Companies must invent tomorrow's manufacturing technology.

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STUART BRADFORD

The Big Question

Manufacturing in the Balance

Inexpensive labor has defined the last decade in manufacturing. The future may belong to technology.

● When General Electric expanded manufacturing of home heaters and refrigerators at its facility in Kentucky last year, the reasons included big wage concessions the company had won from local workers and the advantages of being closer to its U.S. customers. But writing in the *Harvard Business Review* last March, CEO Jeffrey Immelt explained that one of the biggest factors in GE's decision to bring back manufacturing from China and South Korea was the desire to keep appliance designers near its manufacturing and engineers.

"At a time when speed to market is everything, separating design and development from manufacturing didn't make sense," Immelt wrote. Now, someone who has an idea for a dishwasher that has fewer parts and weighs less can actually try to build it. These designs won't →

be so quick to end up in knockoff products built by GE's suppliers, either. "Outsourcing based only on labor costs is yesterday's model," Immelt said.

Near the turn of this century, manufacturing wages in southern China were 58 cents an hour, just 2 percent of U.S. levels. GE and many other manufacturers rushed to take advantage of so-called labor arbitrage by moving manufacturing overseas. In 2004, the Boston Consulting Group told clients the choice wasn't whether to go offshore but "how fast."

The strategy adopted by multinational conglomerates, whether based in the U.S. or in Europe, was simple: substitute inexpensive labor for capital. Why invest in a machine to assemble iPhones when Chinese companies could throw half a million workers at the problem? The Internet, telephones, and affordable air travel and sea shipping made it easier than ever to coördinate labor from afar.

Partly as a result, the U.S. lost about six million manufacturing jobs—33 percent of the total—between 2000 and 2010, and China has overtaken the U.S. as the world's largest producer of manufactured goods. But the impact extends beyond macroeconomic statistics.

In *Producing Prosperity*, a book published last year, Harvard Business School professors Gary Pisano and Willy Shih call offshoring of manufacturing a "grand experiment in de-industrialization." They and others now believe that the consequences have been unfortunate because innovation is hard to separate from manufacturing in technologically advanced areas. Without understanding the details of production, you can't really design the most competitive products. Eventually, what Immelt calls "core competencies"—such as product design and understanding of materials—are put at risk.

$0.58

Hourly compensation of Chinese manufacturing employees in 2002

2.1%

Chinese wages as a percentage of U.S. manufacturing wages in 2002

Lately, however, economic trends have been turning. Wages in China's southern cities have been rising fast and may soon reach $6 an hour, about what they are in Mexico. Boston Consulting Group—the same consulting firm that told clients to run, not walk, overseas—now says it's time to "reassess" China and estimates that for some products, that country's overall cost advantage could disappear by 2015.

The vanishing comparative advantage of Asian cheap labor isn't the only reason for companies to question offshore manufacturing. Natural catastrophes can occur anywhere, but the risks of long supply lines became apparent in 2011, when the Japanese earthquake and tsunami interrupted shipments of computer chips and floods in Thailand left disk-drive factories under 10 feet of water.

Meanwhile, higher oil prices have quietly raised the cost of shipping goods. And a bonanza of cheap natural gas has made the U.S. a relatively cheap place to manufacture many basic chemicals and is providing industries with an inexpensive source of power.

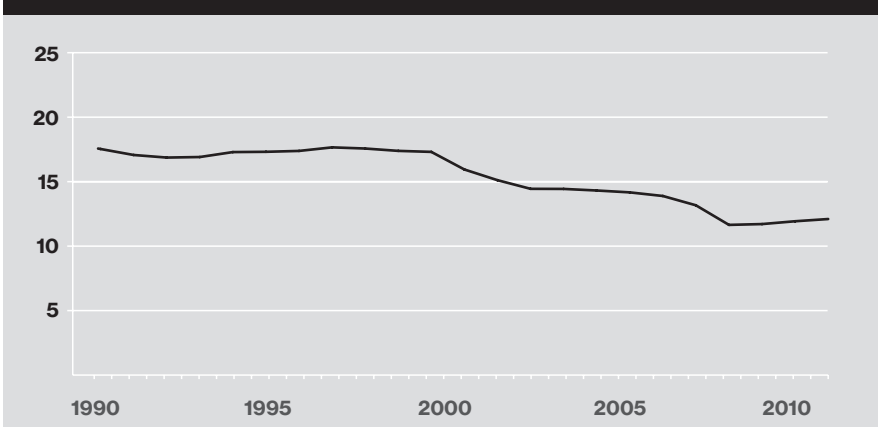
The kind of manufacturing in which labor costs are most important isn't ever coming back from low-wage countries (assembling five million iPhones for a product launch can still only be done in China), but the recent economic shifts are giving companies a chance to adjust course. One major line of thinking, the one most vocally endorsed by the White House, and by President Barack Obama, is that the U.S. should focus its efforts on advances in the technology of manufacturing itself—the set of new ideas, factory innovations, and processes that are also the focus of this month's *MIT Technology Review* business report.

The U.S. holds advantages in many advanced technologies, such as simulation and digital design, the use of "big data," and nanotechnology. All of these can play a valuable role in creating innovative new manufacturing processes (and not just products). Andrew McAfee, a researcher at MIT's Sloan School of Business, says it's also hard to ignore coming changes like robots in warehouses, trucks that drive themselves, and additive manufacturing technologies that can create a complex airplane part for the price of a simple one. The greater the capital investment in automation, the less labor costs may matter.

Because manufacturing is so heterogeneous, no single technology can define its future direction. But for advanced economies like the U.S., the questions don't change. Says McAfee: "If labor is not the differentiating factor, you need to ask, 'What can be?'"

—Antonio Regalado

After Sharp Fall, a Comeback for Manufacturing?
Number of U.S. manufacturing jobs, in millions



DATA FROM U.S. BUREAU OF LABOR STATISTICS

Leaders

You Must Make the New Machines

Economist Ricardo Hausmann says the U.S. has a chance to invent tomorrow's manufacturing technology.

● The U.S. has lost millions of manufacturing jobs since 2000. Industries have moved offshore. America's trade deficit in physical goods is $738 billion a year.

So what's the path forward?

Countries trying to understand what's next for their export industries often call Ricardo Hausmann. The Harvard economist and onetime planning minister for Venezuela has developed a kind of economic aptitude test for nations. Using complexity theory and trade data, Hausmann looks at what a country is good at making and predicts what types of more valuable items it could produce next.

That sounds plain enough, but the results of Hausmann's analyses are often surprising. A country with a competitive garment industry might want to move into electronics assembly—both need an industrial zone with quality electrical power and good logistics. One that exports flowers may have the expertise in cold storage needed to spark an export boom in fresh produce.

Hausmann, director of Harvard's Center for International Development, spends much of his time helping nations that are just beginning to modernize their industries, such as Angola and Nigeria. *MIT Technology Review* asked him what his research methods predict about opportunities for manufacturing in the United States.

Why has the number of American manufacturing jobs been decreasing so quickly?
The fundamental reason is that productivity in manufacturing has been rising rapidly and demand for manufactured products has been growing more slowly. To supply the stuff that people want requires fewer jobs.

And then, manufacturing is becoming feasible in more parts of the world. There is more competition, including from countries with lower wages. As they emulate American production, they take market share.

What's the best manufacturing strategy for the U.S. in that situation?
It's certainly not playing defense and trying to save jobs. The U.S. has very, very high wages compared to other countries. Yet it also has a comparative advantage, which is high R&D intensity, and the best science and technology base in the world.

The step that makes the most sense for the U.S. is to become the producer of the machinery that will power the next global manufacturing revolution. That is where the most sophisticated products are, and that is the work that can pay higher wages.

Ricardo Hausmann advises governments on what to manufacture.

What kind of revolution will it be?
My guess is that developments around information technology, 3-D printing, and networks will allow for a redesign of manufacturing. The world will be massively investing in it. The U.S. is well positioned to be the source of those machines. It can only be rivaled by Germany and Japan.

You look at economies as "product space." What do you mean by that?
The product space is the space of all possible products. The metaphor is of a forest. Each product is a tree, and companies are monkeys that are taking over the forest. Empirically, we've shown monkeys don't fly. They move to nearby trees, or to industries for which they have many of the required productive capabilities.

So if you have the capability to make a regional jet, you may be able to make a long-haul aircraft. But if you are making only garments, figuring out how to make any kind of jet will be very hard. Countries that grow find a "stairway to heaven"—a sequence of short jumps that gets them far.

How does that type of analysis help a country know what to do next?
Think about a developing country that exports raw commodities. The way that people have thought about it is to add value: if you have trees, try to export paper or furniture rather than wood.

But product space may argue against adding value to raw materials. The way a country like Finland got transformed is it moved from cutting wood to making machines to cut wood, to making machines that cut other things, to making other machines, and eventually to Nokia.

So what are the opportunities for the U.S. in product space?
The U.S. has the problem that it's competing with countries that pay much lower wages. American monkeys are under stress from other countries' monkeys in regard to less complex, easier-to-make products. →

CRIS BOURONCLE/GETTY IMAGES

So the U.S. should look to the taller trees. The tallest trees in product space are pharmaceuticals, chemicals, and machinery. It's very hard to get into those. Very few countries are in that game. The U.S. can grow by using capabilities that few others have.

Is there a manufacturing technology you see as game-changing?
I think 3-D printing could change the dynamics. I use 3-D printing as shorthand for shorter production runs, more design, and much closer to the market. It's a paradigmatic shift in what manufacturing is going to look like. Historically you think of manufacturing as an assembly line with thousands of workers and benefits. But here we are talking about very small batches, made close to consumers, and customized. It will still be manufacturing, but a different kind of job in a different kind of company.

Will the U.S. create jobs in this way?
If anything, a manufacturing revolution is going to accelerate a trend toward more efficiency. For the U.S. to base its employment strategy on manufacturing sounds unrealistic. Manufacturing is low-employment.

What else is the U.S. good at producing?
If you look broadly at the U.S. product space, the country is super-competitive at agriculture and industries that support it, like farm machinery, agrochemicals, and genetically modified seeds. It is strong in aerospace and pharmaceuticals, and it is the clear leader in information technology. New industries often arise from the combination of capabilities, such as biotechnology that moves from medicine to seed development.

Is the U.S. staying competitive?
For a while now, the U.S. has been much less focused on being competitive than most other places are. Americans have the feeling they are born to win, and if they don't, someone else is cheating. The U.S. has many self-inflicted wounds. It has an infrastructure that's increasingly lousy, a corporate tax rate higher than most countries', and, worst of all, an immigration policy that prevents the attraction and retention of the high-skilled people who come here to study and then don't stay. *—Antonio Regalado*

Emerged Technologies

What Yoda Taught Me about 3-D Printing

Inexpensive 3-D printers aimed at consumers are toys, not factories.

● Will we one day find a desktop factory in every American home? That's what enthusiasts of 3-D printing technology believe.

To find out how plausible such predictions are, I sat in on a 3-D printing class at the San Francisco branch of TechShop, a studio for tinkerers and designers, where I found myself waiting to see a palm-sized toy model of the *Star Wars* character Yoda materialize from a spool of cheap fluorescent green plastic.

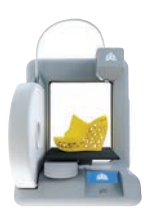
Unfortunately, the classroom's 3-D printer, a desktop model made by the Beijing-based Delta Micro Factory, was acting finicky. Though my instructor had recently replaced some parts, he was now on his fifth attempt to demonstrate how we could print out Yoda from a file he'd downloaded from the Internet. As a stringy nest of half-melted thermoplastic accumulated on the printer's platform, he acknowledged that this Yoda simply wasn't meant to be.

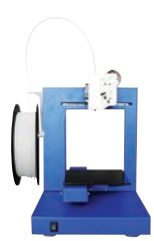
Manufacturing and design companies have already found powerful uses for high-end 3-D printers to quickly produce prototypes and make customized parts on demand. What's said to be coming next is a consumer mass market, and perhaps a radical economic shift as consumers stop shopping and start making what they need.

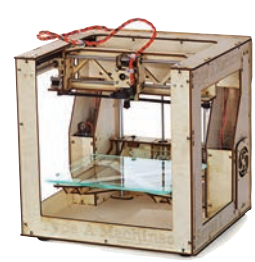
Fueling such thinking is a rapid increase in the number of affordable 3-D printers. The winter 2013 issue of *Make* magazine, a publication for hobbyists, lists 15 different models, with prices starting around $500. The head of MakerBot, a company that recently opened a fancy retail store in Manhattan to sell $2,199 3-D printers, has called the technology the start of "the next industrial revolution."

The term "3-D printing," coined at MIT in the mid-1990s, describes a set of meth-

Consumer 3-D Printers
Printers that let people print objects from plastic at home







Cube	Up! Plus	Series 1
Print volume: 5.5 inches per side	Print volume: 5.5 inches per side	Print volume: 9 inches per side
Price: $1,299	Price: $1,499	Price: $1,400
Introduced: January 2012	Introduced: 2010	Introduced: June 2012
Manufacturer: 3D Systems	Manufacturer: Delta Micro Factory	Manufacturer: Type A Machines

SOURCES: 3D SYSTEMS; DELTA MICRO FACTORY; TYPE A MACHINES

ods that vary widely in price, complexity, and capability. Industrial 3-D printers cost $75,000 and more, and some can build from materials including steel.

Most consumer models use a relatively simple process called fused deposition modeling, invented and patented in the late 1980s. As in a hot-glue gun, a length of special plastic is melted and fed through a nozzle. As gears guide the nozzle up, down, and around over a platform, the plastic is deposited in layers that harden, and a three-dimensional object takes shape.

The big drawback for consumers is that 3-D printers are still tricky to use and very limited in what they can make. The objects they produce are not just fairly crude but quite small, since the thermoplastic will warp at larger sizes. What's more, thermoplastics are just the kind of cheap, brittle material many people hate. The hardware requires precise calibrations that will be beyond the patience of many users, and operating the software is significantly more complicated than clicking "Print" from a Word document.

Another problem: once you've made yourself an iPhone case and a Yoda bust, what else is worth making? The answer is not entirely obvious, says Eric Wilhelm, founder of Instructables, an online catalogue of how-to tutorials. Wilhelm, who has been tracking the 3-D designs being created, says the bulk of them are models of people's heads, often their own.

The constraints of the at-home technology explain why the latest shift in consumer 3-D printing is toward centralized facilities not unlike photocopy shops. Last year, the office store Staples said it would test a service called "Staples Easy 3-D": customers could send in a design and then pick up the finished product. Another company, Shapeways, has opened the largest such facility yet, in New York City. It aims to print three to five million objects a year on higher-end printers, using materials that include ceramics and silver.

According to the online price calculator Shapeways offers, a version of my four-inch-tall plastic Yoda would cost about $20, with a delivery time of eight to 14 days.

As the ancient Jedi himself might have said: "Order one, I will not." —*Jessica Leber*

GE's advanced battery plant in Schenectady is a testbed for the "industrial Internet."

Emerged Technologies

An Internet for Manufacturing

Imagine a factory where every product remembers how it was made.

● What is the industrial Internet?

As good a place as any to find the answer is at General Electric's newest U.S. factory, a $170 million plant it opened in Schenectady, New York, last July to produce advanced sodium-nickel batteries for uses that include powering cell-phone towers.

The factory has more than 10,000 sensors spread across 180,000 square feet and connected to a high-speed internal Ethernet. They monitor things like which batches of powder are being used to form the ceramics at the heart of the batteries, how high a temperature is being used to bake them, how much energy is required to make each battery, and even the local air pressure. On the plant floor, employees with iPads can pull up the data from Wi-Fi nodes set up around the factory.

In November, GE announced it would invest $1.5 billion in efforts to fine-tune its machines' performance and capture big efficiency gains by connecting them to its enterprise software and to the wider Internet. Although the idea of networking machinery isn't new, GE thinks that cheaper computing power and sensors are now poised to usher in a new era of big data for industry. Jeff Immelt, GE's CEO, has called the idea a revolution, and the company's top economist has suggested it could help increase worker productivity by as much as 1.5 percent a year.

Those are big claims, and GE's heavy spending at Schenectady was meant partly to show off its plans. Every part that goes into the batteries gets tracked with serial numbers and bar codes; if managers want to assess how much energy it took to make a specific battery part and compare it with the average, or study a day's production, they can do ad hoc analyses on powerful workstations. "I've never been able to do that before," says Randy T. Rausch, business analytics and manufacturing information leader at GE Energy Storage. →

$1.5 billion

GE's proposed investment in the industrial Internet

KEVIN BULLIS/MIT TECHNOLOGY REVIEW

The sensor data has yielded some useful insights, says Rausch, including the finding that some battery parts failed quality tests after spending too much time on the manufacturing line. GE now tracks how long parts "soak" in the factory's ovens and how much time they spend elsewhere on the production line; alarms flash near those approaching their limit.

With its push for the industrial Internet, GE may find it's selling an idea that some manufacturers aren't convinced is really new. Down the road from GE's Schenectady plant, in Cohoes, New York, Mohawk Fine Papers already monitors how much energy its machines use, pulling together the data in an analytics program it bought from a company called OSISoft. "A lot of the basics of what we're talking about have been available to companies for years," says Kim E. Osgood, Mohawk's director of engineering and energy services.

GE will need to show the benefits of bigger networks and more data, something Rausch is working on. The battery factory has more than 100 air pressure, humidity, and temperature sensors, and Rausch hopes to use weather forecasts to control how much outside air the HVAC system lets in. Since temperature and humidity can affect batteries, Rausch says, "we'd like to [be] able to know when the humidity is changing and open and close the vents sooner."

The industrial Internet is now really more of an intranet—most data never leaves a factory or a company's firewall. But eventually, says Rausch, the idea is to track batteries even after they leave the plant, using embedded computer chips. Other GE divisions have similar plans for keeping tabs on people's refrigerators and dishwashers.

With what GE knows about every washing machine and battery it sells—what day it was made, how it was made, who made it—the goal will be to draw connections between products that perform better or worse in actual use and the conditions under which they were made.

Those links, the ones between the outside world and the factory floor, could ultimately be the most valuable. "It's where we want to end up in a couple of years," says Rausch. —*Michael Fitzgerald*

President Barack Obama addresses manufacturing workers in 2012.

AP/MATT SLOCUM

Leaders

Obama Push on Advanced Manufacturing Stirs Economic Debate

In a White House switch, pro-manufacturing advisors have the ear of the president.

● Before a packed arena at the national convention of the Democratic Party in September, Barack Obama outlined a vision for America's economic recovery with manufacturing as its engine.

"After a decade of decline, this country created over half a million manufacturing jobs in the last two and a half years," Obama told the cheering crowd in Charlotte, North Carolina. "If we choose this path, we can create a million new manufacturing jobs in the next four years."

To fulfill such promises, the White House is turning to a tool not seen in Washington for years: industrial policy.

Emboldened by a new cadre of advisors, the Obama administration has proposed policies to boost domestic manufacturing—tax breaks, new R&D spending, and vocational training for two million workers in areas including advanced technologies like batteries, computing, aerospace, and robotics.

The idea is that manufacturing—especially the kind involving cutting-edge techniques or products—is so closely tied to American technological creativity that these industries must be protected from the kind of overseas competition already blamed for destroying the U.S. position in flat-panel displays and machine parts.

The proposals, set in motion in 2011, represent a remarkable shift in U.S. thinking because the country has not had an explicit industrial policy since the Carter era. It has also stirred a rancorous debate among economists, some of whom say the White House has made a break from mainstream thinking.

That debate burst into the open last February, when economist Christina Romer, the former chair of Obama's Council of Economic Advisers, questioned in a column for the *New York Times* whether manufacturers need "special treatment."

9%

Percentage of U.S. workers employed in manufacturing

Taking aim at key elements of the White House proposals, Romer said there was little evidence that manufacturing will create significant job growth or stop a slide in middle-class incomes. She disputed the idea that manufacturers should get breaks not available to, say, a software company.

"So far, a persuasive case for a manufacturing policy remains to be made," wrote Romer. Without hard evidence, she said, White House policy boiled down to no more than "feeling that it's better to produce 'real things' than services."

But an entirely different school of thought is now ascendant in the White House, one arguing that manufacturing, even though it employs only 9 percent of U.S. workers, plays an outsize role in the economy. For instance, manufacturing companies carry out around two-thirds of all corporate R&D and file the most patents. There is evidence that factories may yield knowledge "spillovers" that improve the broader economy. "Within this administration there's been a reframing," says Mark Muro, a senior fellow at the Brookings Institution, a Washington think tank. "The folks on the inner circles of the White House now are strikingly sympathetic to manufacturing and see it as critical."

At the center of that shift is Gene Sperling, a lawyer Obama chose to replace Harvard University professor Larry Summers as director of the National Economic Council in 2011. As cochair of the White House's Office of Manufacturing Policy, the Michigan native has been an architect of Obama's manufacturing agenda and has brought on like-minded advisors.

The White House did not respond to a request for comment, but Sperling is known as a savvy political operative. He is "very different in his orientation" from academic economists, says Rob Atkinson, president of the Information Technology & Innovation Foundation. "This is why this [policy shift] has happened now rather than before."

Sperling's group believes that government can and should prevent the decline of U.S. manufacturing. "When we remain indifferent to the decision to compete for the manufacturing products of the present," he said last March in a policy speech that rebutted Romer and other critics, "it can trigger the loss by our nation of the ability to … create the next generation of technologies."

Under Sperling's leadership, the White House has proposed a series of measures to accelerate advanced manufacturing, including an additional $418 million for R&D (a 19 percent increase); a bundle of tax breaks; and a $1 billion program to create 15 national institutes aimed at developing manufacturing techniques in areas such as 3-D printing and nanotechnology.

The government's approach has a committed chorus of supporters. In February, the Brookings Institution released a paper arguing for a manufacturing policy similar to that of Germany. That country, which carefully manages its manufacturing sector, still maintains a trade surplus with China and has lost fewer of its manufacturing jobs than the U.S. has.

Yet some White House proposals are considered unorthodox. One proposed rule change, for instance, would double the "domestic production" tax break for companies that do advanced manufacturing but eliminate it for oil producers. Another tax write-off, for scrapping equipment, wouldn't be available to any company moving its operations and jobs overseas.

Even though many businesses, including farmers, get big subsidies, new tax rules that favor certain industries over others are likely to be sharply opposed in Congress. "The dominant view in Washington is that that is inappropriate tax policy," Atkinson says. "This [will be] a huge uphill battle."

—Walter Frick

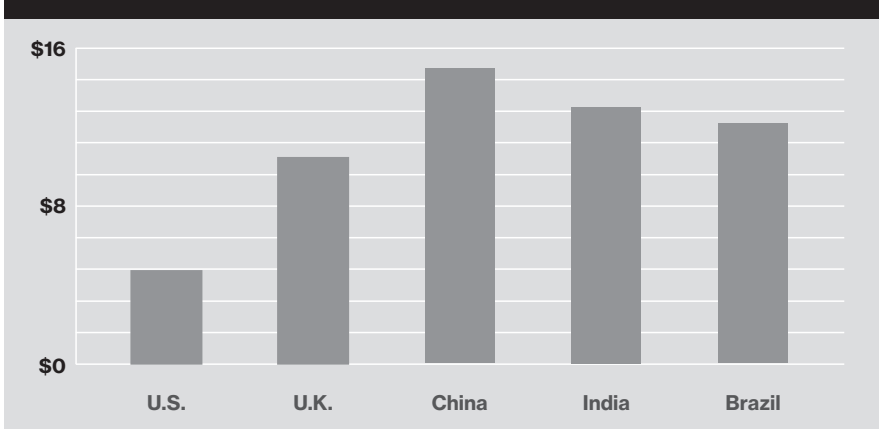
Case Studies

Shale Gas Will Fuel a U.S. Manufacturing Boom

Chemical producers abandoned the U.S. in droves. Cheap natural gas is luring them back.

● People predicting a manufacturing renaissance in the United States usually imagine whirring robots or →

Cheap Fuel
Natural gas prices vary widely (dollars per million BTUs for liquid gas, January 2013).



SOURCE: WATERBORNE ENERGY

advanced factories turning out wind turbines and solar panels. The real American edge might be in something entirely more mundane: cheap starting materials for plastic bottles and plastic bags.

$300

Approximate cost to produce a ton of ethylene in the U.S. in 2012

$148 billion

Global ethylene sales each year

The plummeting price of natural gas—which can be used to make a vast number of products, including tires, carpet, antifreeze, lubricants, cloth, and many types of plastic—is luring key industries to the United States. Just five years ago, natural-gas prices were so high that some chemical manufacturers were shutting down U.S. operations. Now the ability to access natural gas trapped in shale rock formations, using technologies such as hydraulic fracturing and horizontal drilling, has lowered American prices to a fraction of those in other countries.

Over the last 18 months, these low prices have prompted plans for the construction of new chemical plants to produce ethylene, ammonia for fertilizer, and diesel fuels. Dow Chemical, for example, plans to spend $4 billion to expand its U.S. chemical production, including a new plant in Freeport, Texas, that's due to open in 2017. The plant will make ethylene from the ethane found in many sources of natural gas. (The last such plant to be built in the United States was completed in 2001.)

The impact of the resurgence is being felt most strongly in the $148 billion market for ethylene, the world's highest-volume chemical and the foundation for many other industries. It's used to make bottles, toys, clothes, windows, pipes, carpet, tires, and many other products. Since ethylene is expensive to transport over long distances, a new ethylene plant is typically integrated with a facility to convert it into polyethylene for plastic bags or ethylene glycol for antifreeze.

In the U.S., it costs $300 to make a ton of ethylene, down from $1,000 a few years ago, according to an analysis by PricewaterhouseCoopers published in October. It costs $1,717 to make it in Asia, where plants depend on high-priced oil instead of natural gas, and $455 per ton to make it in Saudi Arabia, using a combination of ethane and butane. (Ethylene plants are also being built in Qatar, which, like the U.S., has very cheap natural gas.)

Over the last two years, manufacturers have announced plans to add 10 million metric tons of ethylene capacity in the United States by 2019. Those plans represent a 10 percent increase in global ethylene production and also account for close to half the industry's planned expansions in all countries.

The impact of cheap natural gas on manufacturing could extend beyond the production of various chemicals. Using natural gas as an energy source, rather than as a chemical feedstock, could significantly lower costs for manufacturers who use a great deal of energy, such as steel makers. (The steel industry is booming already for another natural-gas-related reason—it's supplying gas producers with pipes.) What's more, cheap natural gas is prompting a shift away from petroleum-based fuels for trucking. Some companies are switching to trucks that burn natural gas directly. Eventually, even diesel trucks could be using fuel made from natural gas. The South African company Sasol plans to build a huge $14 billion plant in Louisiana partly to convert natural gas to diesel, potentially lowering fuel costs for conventional vehicles as well.

Overall, cheaper chemicals, cheaper steel, and cheaper transportation could make the United States a far more attractive place for a wide range of industries.

Still, Michael Levi, a senior fellow at the Council on Foreign Relations, says energy doesn't exceed 5 percent of costs in most industries—not enough to make gas prices decisive for most companies when they're deciding where to build manufacturing plants. Levi thinks the biggest difference cheap energy might make is to give existing U.S. factories a new reason not to close or move offshore. "Cheap natural gas might do more to keep existing manufacturing plants open than it will to get people to build new ones," he says.

Just how long U.S. natural gas will stay relatively cheap is not clear. For capital investments to pay off, say analysts, oil prices need to stay high, and gas prices low, for many years to come. That means chemical makers could still shift their plans. For instance, Sasol will reassess the economics of its planned plant for converting natural gas into diesel in 2014, before it breaks ground.

—Kevin Bullis

STUART BRADFORD

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Reviews

HARRY CAMPBELL

Design over Usability

Windows 8 gets a lot right, but Microsoft's determination to offer computer and mobile users the same interface makes the operating system somewhat weird.

By Simson Garfinkel

Microsoft Windows 8
Upgrade, $39.99

Windows 8 is a computer science masterpiece trapped inside a user interface kerfuffle. Microsoft's new operating system for phones, tablets, laptops, desktops, and servers brims with innovative technologies, bold ideas, and visual elegance. The system's radical new interface, called Modern, is a pleasure to use on phones and tablets. And although that interface fares poorly on today's larger desktop computer screens, Windows 8 probably won't damage the company's standing in corporate America. It might even shore up its eroding presence on residential desktops and laptops by offering a user experience that's new, fun, and different from anything offered by Apple and Google. Indeed, that's my only real criticism of Windows 8: the touch-based user interface is clearly designed for consuming

information and having fun, rather than for doing serious work.

It makes technical sense for Microsoft to maintain a single, core operating system with a consistent set of application programming interfaces (APIs). In fact, it makes so much sense that Apple and Linux moved to a single kernel years ago. What's different about Windows 8 is that it gives users a similar graphical user interface (GUI) on every platform, too. Microsoft has spent more than a decade trying to get cut-down versions of its operating system, with names like Windows CE, Pocket PC, and Windows Mobile, accepted on mobile platforms. Some of these systems even had scaled-down versions of the standard Windows desktop interface—complete with pop-up windows, buttons, scroll bars, and even tiny Start buttons. But their GUIs and APIs were just different enough to confuse programmers and users alike. Windows 8 finally delivers consistent GUIs and APIs across the Microsoft ecosystem, although it is now the desktop that wears the tablet's clothes.

While many critics have decried Windows 8 as another Microsoft misstep, I think they're wrong.

It's easy to find things that are wrong with Modern (which was called Metro in developer and early versions). For example, there are no overlapping windows, and there's simply no way to put three or four applications on a single screen at the same time—even if your work space has a screen that's 27 inches across. Windows 8 largely eliminates menus—the product of more than 40 years of usability research—and introduces a new system of touch-based text labels and controls that are frequently hidden and obscure. The interface is sparse—applications like e-mail and the address book now present far too little information on the screen, resulting in the need to frequently pan and scroll.

Complicating our understanding of whether these are bugs or features is the departure of Steve Sinofsky shortly after the product's launch. Sinofsky, who had been president of Microsoft's Windows Division and was seen as a likely successor to Microsoft chief executive Steve Ballmer, was the very public face of the redesign. He spent more than a year documenting many of the more radical departures in his blog, Building Windows 8, with detailed posts that were supported with telemetry data captured from the millions of users who participated in the Windows Customer Experience Improvement Program. Microsoft will never admit that Windows 8 is a colossal mistake, but was Sinofsky's sudden departure an admission of sorts that some of the changes were just too radical? Will they be undone in some soon-to-be-released Windows 8.5?

While many critics have decried Windows 8 as another Microsoft misstep, I think they're wrong. After using the new operating system in all its incarnations on a phone, on Microsoft's Surface tablet, and on several desktops, I've come to regard it as truly transformative. Windows 8 will well serve the needs of those non-technical users who just want to access their online social networks, watch Netflix, and go shopping—especially since the underlying system provides more security while making it easier for them to find, download, and install their (Microsoft-approved) apps. Windows 8 does a poor job of catering to knowledge workers like me who earn a living by synthesizing information from multiple data sources or use application programs that have hundreds of specialized features. But those brain-heavy office workers do not represent Microsoft's present or future. Last year, Microsoft made just $18 billion (24 percent) of its $74 billion in revenue from the sale of Windows operating systems. Its real moneymakers in the corporate world are not operating systems for desktops but applications like Office and servers like Exchange. Many of Microsoft's corporate and government users are only now upgrading from Windows XP to Windows 7. Few corporate IT departments will immediately deploy Windows 8 to their desktops: they can continue to support older versions of the operating systems for years, or until Microsoft releases a version of the new operating system that's appropriate for offices. Windows 8 doesn't need to be an efficient, productive-business-oriented operating system to be a success; it needs to win the home market by making laptops and desktops as much fun to use as phones and tablets.

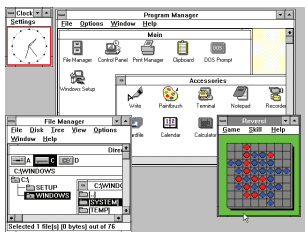
Fast, Connected, and Secure

The idea of a single operating system to be deployed on all computing platforms—from the slowest of cell phones to relatively high-performance laptops and desktops, and even supercomputers—has clear technical benefits for users. Consider power efficiency: new algorithms and data structures inside the core of an operating system can let the kernel perform more functions while executing fewer instructions. Such changes extend the battery life when the OS is run on a cell phone. On a server in a data center, those same changes will lower electricity and cooling bills.

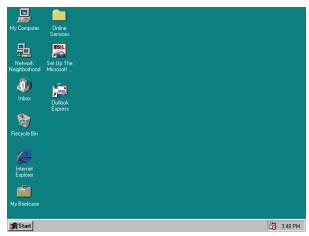
Developers also benefit from having a single OS. For example, it means that the same tools can be used to develop applications for all platforms, so advances can be made immediately available across the entire product line. A single OS with the same set of APIs also means that a programmer with experience working on, say, cell phones can be rapidly reassigned to work on a cloud-based application.

Apple and Google learned this lesson years ago. Apple runs nearly identi-

Windows through the years



1990
Windows 3.0
Based on MS-DOS, with an ugly but functional user interface.



1995
Windows 95
Pretty icons and windows, but still based on MS-DOS.

2001
Windows XP
Microsoft's first stable desktop OS, based on the NT kernel.

2009
Windows 7
A rock-solid OS that corporations are only just now adopting.

cal software stacks on its iPhone, iPad, laptop, and desktop systems: the main differences are inconsistencies caused by different input devices (touch screen vs. mouse) and different release cycles. Similarly, Google's Android phones use versions of the same Linux kernel that's found in data centers.

With Windows 8, Microsoft joins its competition in having the same kernel, API, and developer tools on all its platforms. The advantage is evident from the moment you turn on a Windows 8 machine. A consumer-grade Dell desktop that I tested took just 20 seconds to boot Windows 8; that same hardware took nearly a minute to start Windows 7.

Those versions of Windows 8 all benefit from a newfound commitment to connectivity as well. I easily configured my Windows phone to upload snapshots to SkyDrive, Microsoft's cloud-based storage system. The photos could then be downloaded automatically to my other Windows 8 machines.

Office can also save files on SkyDrive; then you can edit them from any Internet-connected computer with the cloud-based version of Office. Microsoft is late with such file-sharing services—Apple, Dropbox, and Google all have similar offerings—but Microsoft has done a better job of integrating them directly into the operating system.

The new cloud-based Windows services do a better job with account authentication, too. Windows 8 lets you use the same Live.com username and password for tablets, desktops, and laptops, so you can change your password once for all those devices—a feature previously available in many enterprise environments but not to home or small-business users.

Somewhat surprisingly, Windows 8 also integrates with Facebook, LinkedIn, Twitter, and even Google. Give it your online usernames and passwords and the People tile on the Start screen will come alive with photos taken from friends' Google+ and Facebook profiles. Touch the tile and each person's address-book entry will be augmented with his or her tweets and Facebook posts. Microsoft's mail application can grab a feed from your Gmail in-box. Underneath the user interface, Windows has introduced many important security improvements as well. Windows 8 supports a new feature called Secure Boot, which verifies each time the OS starts up that it hasn't been tampered with or otherwise modified. A free copy of Microsoft's antivirus software is enabled by default. Updates download every day, with no subscription necessary. Even encryption is beefed up: for example, the built-in mail client won't send your password over the Internet unless the link is encrypted and the server has a valid SSL certificate. Windows 8 also enforces stronger security policies on developers, requiring that all approved applications run in a restricted environment called the AppContainer—a kind of sandbox that limits the damage a rogue (or exploited) application can do.

The waste of screen real estate becomes increasingly evident as the screen gets larger.

Four Windows and Many Apps

Microsoft plans to sell this core Windows 8 operating system in many different variations. For desktops and laptops there are Windows 8 and Windows 8 Pro (the standard version disables full-disk encryption and remote access features). Although upgrading a computer from 7 to 8 is painless, largely automatic, and cheap (in January the downloadable upgrade cost just $39.99), most users will want to get new hardware to take advantage of touch-based input. Consumers can expect to see a surge in "convertible" laptops that double as tablets, as well as LCD screens with touch-panel overlays.

Microsoft's new Surface tablet runs Windows RT (RT stands for runtime), which has fewer features than the desktop OS, although visually it's hard to distinguish between the two. The big difference is inside: the Surface is built upon the low-power ARM microprocessor, the same processor as in most Android tablets

WINDOWS 3.0, 95, XP: USED WITH PERMISSION OF MICROSOFT; WINDOWS 7: FLICKR/BURHAN FADZIL; WINDOWS 8: FLICKR/OKUBAX

2012
Windows 8
Each tile is a window to a different full-screen app.

and phones (and similar to what Apple has in the iPhone and iPad). Because the ARM's instruction set is different from that of traditional x86-based systems, RT runs only a tiny subset of today's Windows applications. Easing that sting, RT comes with a version of Microsoft Office that includes Word, Excel, and PowerPoint. RT's Office lacks key features used by some corporate customers, such as the ability to execute embedded programs called macros and a copy of Outlook that connects to Exchange servers. It's probably not a big deal: macros have security problems that IT managers deplore, and RT comes with other apps for e-mail, address book, and calendar functions. New applications written for Windows RT will run on both x86 and ARM-based computers without modification, thanks to Microsoft's Common Language Runtime (CLR), which uses the same sort of "write once, run anywhere" approach to hardware independence that characterizes the Java programming language.

Phones such as the Nokia Lumia 920 run Windows Phone 8. These phones are also built on an ARM processor and, like the other versions of Windows 8, have a heavy emphasis on touch. Developers may thus create a single code base in order to develop apps that will run on Windows Phone 8, Windows RT, and Windows 8 desktop systems, much the way Apple developers can write a single app for an iPhone and iPad. As with the Apple systems, different screen sizes mean the app will need to display a slightly different user interface on each platform, but the app's internal logic (which is typically the most expensive part to develop) will largely remain the same.

Apps are the future of Windows. That's a positive trend for usability and security, but it will also reduce the freedom of mobile-device users. Although Windows 8 desktops allow users to install apps from any location, the phone and tablet versions will only accept apps from the Windows Store. Likewise, Windows RT will run Adobe Flash only on websites that have been preapproved by Microsoft. While the Windows Store doesn't have nearly as many apps as either Apple's App Store or Google Play, important ones like Netflix and the New York Times are present. I suspect that most Microsoft users will happily accept Microsoft's newfound domination of its own platform … that is, provided they can come to terms with the completely revamped Windows interface.

About That Modern Interface

Back in the 1990s, the big advantage of Windows was something we now take for granted: multitasking. Windows could run multiple programs at the same time, each in its own overlapping window. Windows 8 still runs multiple programs at once, but the windows no longer overlap. Instead, the system confronts the user with a Start screen: a multichromatic strip of tiles, each representing an installed application. Some tiles are flat, static, and monochromatic, while others burst forth with color and even animated video. Click a tile, and that application fills the screen. Users switch applications by going back to the Start screen and clicking on another tile, or by cycling with the application "switcher." It is possible to split the screen between two apps, but that's it.

The advantage of this new interface is that it focuses the user's attention solely on the task at hand: a boon, maybe, for people with attention deficit disorder. The problem is that there is simply no way to see three different apps—or even three Web pages—at the same time. The waste of screen real estate becomes increasingly evident as the screen gets larger. The result is that many tasks become unnecessarily difficult. The famed usability expert Jakob Nielsen has joked: "The product's very name has become a misnomer … the product ought to be renamed 'Microsoft Window.'"

Microsoft's newfound commitment to simplifying the user experience goes far beyond the cult of monowindowism. The Modern interface is largely devoid of status information. My 11-year-old twins were decidedly annoyed that they couldn't make the clock appear on the Surface tablet we reviewed. (To do so, you must go to the Start screen and swipe your finger from the screen's right side.) Windows Phone, meanwhile, was befuddling to a Verizon sales rep I met, who couldn't figure out how to make the phone display the signal strength indicator. (Make it appear by swiping your finger down from the top of the screen to the middle—but this gesture doesn't work if you are using the Web browser.)

The interface's second big departure is something Microsoft calls "charms"—hidden menus that appear with a finger-swipe toward the right side of the screen and contain a mix of controls for the current application and controls for the computer as a whole. Search is implemented this way (swipe right to left and click the magnifying glass), as is the on/off/sleep control (swipe right, click the gear, then click the IEC power symbol). In his damning review of the Modern UI, Nielsen concluded that charms add to the user's cognitive burden because they hide important information under multiple layers of interaction.

Certainly, the Modern interface is beautiful. The typography is light, airy, and very distinctive. The tiles on the Start screen and many of the applica-

tion buttons give the appearance of being pressed down at an angle when they are touched, almost as if they were hinged pieces of plastic suspended from the screen. Sadly, in many places the new design also decreases usability, since the only way to tell if a piece of flat text is a control is by clicking on it. For example, touch the Settings charm on the Start screen and six icons appear for changing settings. Underneath the icons is a label, "Change PC settings." But the text is actually a seventh button that gives access to more PC settings. Previous versions of Windows—and practically every other operating system being distributed today—use 3-D shading to show what's a clickable control.

I found myself touching text, lines, dots, edges, wondering if something useful would happen.

The commitment to touch on laptops and desktops inevitably means that Modern applications show less information on the screen than their Windows 7 counterparts. Microsoft claims that touch is a more natural way of interacting with a computer, but let's be clear: there is nothing natural about interacting with a computer. A finger is a much worse pointing device than a mouse or an on-screen pointer, for the simple reason that fingers obscure what is on the screen, while a mouse doesn't. The low information density is unfortunately inherent in a touch-based, on-the-go device like a phone, but it's an unnecessary inconvenience for knowledge workers sitting at desktop computers with large screens. The Windows desktop remains part of Windows 8 and Windows RT (reachable either through a tile on your Start screen or by using Windows key + D), but without the traditional Start button, users are continually jumping between the two interfaces. Fortunately there are now third-party apps that bring back the Start button.

Get the Phone; Wait on the Desktop

Microsoft's Modern interface delivers a user experience more personalized and enthralling than what either Apple or Google offers. But it's also like a puzzle that you can't quite solve. With controls no longer in a consistent location, I found myself touching text, lines, dots, edges—everything, really—all the time, wondering if something useful would happen. And aspects of this system seem strangely archaic—like the little floppy disk icon to save files, and the little cassette tape icon used to access your voice mail. I doubt that anyone under 25 has ever seen the objects these icons represent.

Microsoft seems determined once again to promote a single user interface for screens of all sizes, but whereas its historical mistake was putting a big-screen interface on a small computer, its new error is putting the small-screen interface on a big one. This may not be a losing strategy: I predict that Windows 8 will be a winner in today's competitive phone, tablet, and convertible-laptop markets. Apple shows no interest in licensing its operating system; Windows 8 lets phone and tablet manufacturers give their users a choice other than Google Android. Back at the office, Microsoft will continue to sell its desktop applications, and those applications will run on the legacy Windows desktops until IT departments see a version of Windows 8 more appropriate to their needs. That future version will probably add back the Start button and give users a few more status bars and menus. Perhaps Microsoft will even allow applications to run in overlapping windows.

Simson Garfinkel is a contributing editor to MIT Technology Review.

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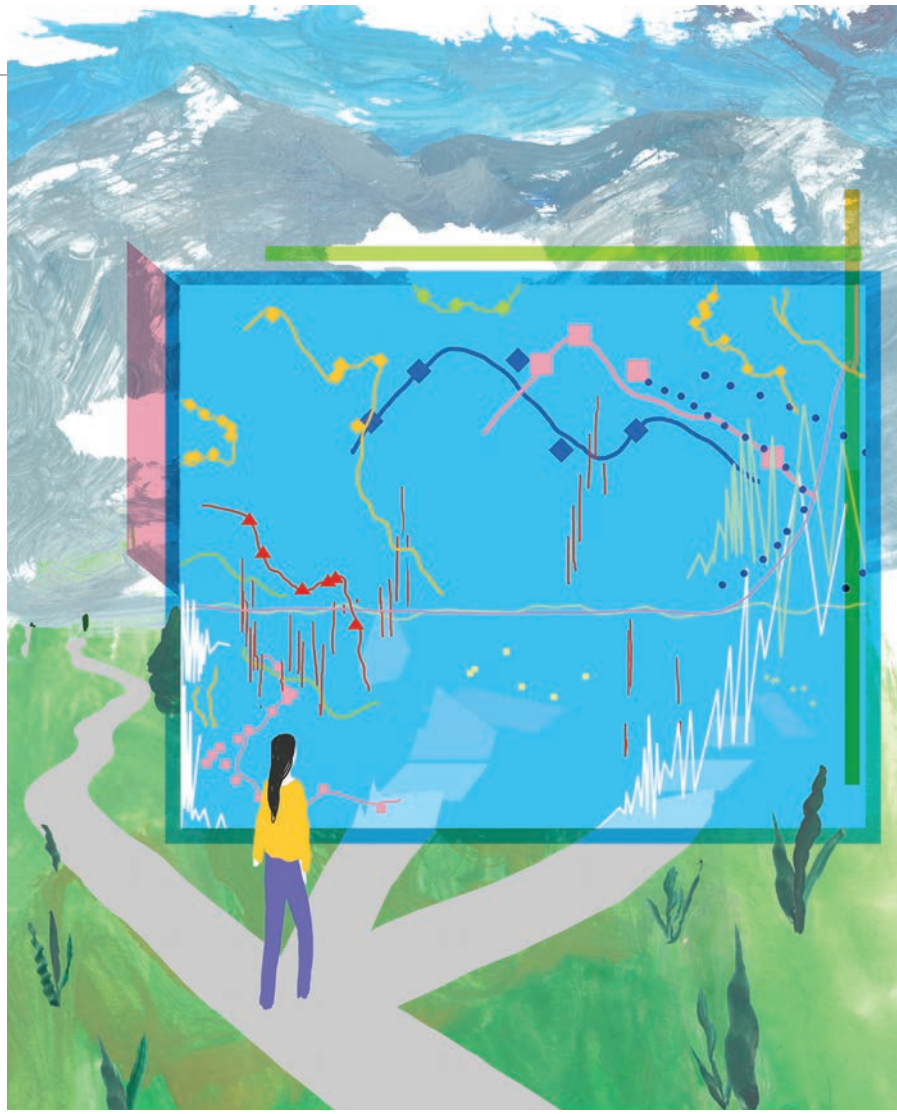

JON HAN

The Problem with Our Data Obsession

The quest to gather ever more information can make us value the wrong things and grow overconfident about what we know.

By Brian Bergstein

A contentious question on the California ballot in 2008 inspired a simple online innovation: a website called Eightmaps.com. The number in the name referred to Proposition 8, which called for the state's constitution to be amended to prohibit gay marriage. Under California's campaign finance laws, all donations greater than $100 to groups advocating for or against Proposition 8 were recorded in a publicly accessible database. Someone (it's still not clear who) took all the data about the proposition's supporters—their names and zip codes, and their employers in some cases—and plotted it on a Google map.

After finding themselves on the map, several supporters of the gay-marriage ban said they were harassed or their businesses were boycotted. This unsettled even some opponents of Proposition 8; surely it wouldn't be long, they said, before, say, religious fundamentalists created a similar tool to call out supporters of a gay-rights measure. The committee that had backed Proposition 8 asked a federal judge to strike down the disclosure law or raise its threshold beyond $100 so that more people could give anonymously. But he refused, arguing that ballot measures need the "sunshine" that donation disclosure provides. His ruling was aligned with the idea that as much data as possible about the political process should be revealed.

Evgeny Morozov worries that we are too often making this trade-off—opting to publish more information to increase transparency even if it undermines principles such as privacy or civic involvement. In his trenchant new book, *To Save Everything Click Here,* Morozov, a writer for *Slate* and *The New Republic,* uses the Eightmaps episode to support his claim that "Internet-centrism" is warping our view of what's truly important.

Transparency is ascending at the expense of other values, Morozov suggests, mainly because it is so cheap and easy to use the Internet to distribute data that might someday prove useful. And because we're so often told that the Internet has

To Save Everything Click Here: The Folly of Technological Solutionism
Evgeny Morozov
Public Affairs, 2013

"Against Transparency"
Lawrence Lessig
The New Republic, October 9, 2009

The Closed World: Computers and the Politics of Discourse in Cold War America
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MIT Press, 1996

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liberated us from the controls that "gatekeepers" had on information, rethinking the availability of information seems retrograde—and the tendency toward openness gathers even more force. (Notice that Facebook says its mission is "to make the world more open and transparent.")

Morozov is not alone in fearing too much transparency. Harvard professor Lawrence Lessig has eloquently described why having more data about politicians is more likely to mislead people into cynicism than to make politics better. But Lessig seems resigned to the inevitability of such data-gathering projects in the age of the Internet. He believes the solution is to finance elections publicly, so people have less reason to be cynical about their lawmakers' motivations.

That infuriates Morozov, because he believes Lessig is merely furthering a misconception that the Internet is like some force of nature rather than a human creation—that resistance is futile. On the contrary, Morozov says, resistance is required. His response to the problem raised by Eightmaps is not to simply accept that more information is going to be easily searchable and change the law accordingly. Instead, we should demand that our online systems respect values beyond mere transparency. Campaign donation databases, for example, could be designed so that records cannot be sucked out of them en masse. Yes, that would inhibit some easy data discoveries. But it could enhance democracy in the long run by making people feel freer to support causes that might be unpopular in their neighborhood or their office.

Morozov's first book, *The Net Delusion: The Dark Side of Internet Freedom*, sought to puncture the myth that social media is a potent weapon against dictatorships. Quite the opposite, he said: savvy regimes use the Web to keep tabs on dissidents. This certainly appears to be true in China, Syria, and Iran. In his new book he is trying to deflate a more amorphous idea: "solutionism." This is his word for the belief that with enough data about many complex aspects of life—including not just politics but also crime, traffic, and health—we can fix problems of inefficiency. For example, predictive software now analyzes crime statistics and helps police decide where to beef up patrols. Algorithms track website clicks and advise journalists on what kinds of stories to write. Morozov sees many ways this could go terribly wrong. For one thing, maximal efficiency is not necessarily a value to strive for; inefficiency often produces social benefits. Not knowing exactly how much readership each story got probably led newspapers to extensive coverage of state government.

Technological Hubris

But the most chilling potential problem is that the data we use to guide ourselves can be incomplete or overly reductionist. Many crimes go unreported, which could fool predictive policing software into thinking a neighborhood is safe. Cops on the beat, however, might be able to tell when things don't seem quite right there and keep an eye out. Morozov fears a future in which such "intuitive knowledge" about how to deploy resources is overruled by algorithms that can work only with hard data and can't, of course, account for the data they don't have. Similarly, online records of someone's campaign donations might seem detailed and hence instructive, but they will always offer at best a partial account of that person's beliefs or role in the political process.

This concept might be Morozov's strongest point: that however objective data may be, interpretation is subjective, and so is our choice about which data to record in the first place. While it might seem obvious that data, no matter how "big," cannot perfectly represent life in all its complexity, information technology produces so much information that it is easy to forget just how much is missing.

This is not a new problem; the deceptive or even blinding qualities of big data plagued the first power users of computing. During the Vietnam War, the U.S. military wanted to stop North Vietnam from using the Ho Chi Minh Trail, a system of jungle passages through neighboring Laos, to send supplies to the communist insurgency in the south. Defense Secretary Robert S. McNamara, who had relied on quantitative management methods while running Ford Motor, did what came naturally: he sought more data about what was happening on the trail. Thus began Operation Igloo White. From 1967 through 1972, American planes flew over the trail and dropped 20,000 battery-powered sensors that looked like plants or wood but could detect voices and other sounds, body heat, urine, and the seismic disturbances particular to trucks. These sensors sent signals to American planes, which relayed the data to a U.S. command-and-control facility in Thailand, where technicians sitting at banks

Life is messy, and not everything can be abstracted into data for computers to act on.

of terminals could see maps of the Ho Chi Minh Trail. When a sensor detected something, that section of the trail lit up like a white worm. IBM 360/65 computers at the center calculated how fast the worm was moving; that information was radioed to U.S. bombers so the area in question could be attacked.

From the control center, Igloo White might have looked pretty good. Worms appeared on the screens and then vanished in bombings. The data seemed to indicate that the Americans had destroyed thousands of trucks and disrupted routes delivering significant amounts of supplies. The military was sufficiently pleased to spend $1 billion a year on the program.

But congressional investigators would eventually cast doubt on the Pentagon's assumptions about how many trucks had been bombed. The communists ultimately weren't deterred from moving supplies southward. They even delivered tanks used in a huge offensive in the south in 1972. It turned out that the Americans didn't realize the extent to which they and their IBM machines were acting on incomplete and unreliable data. For one thing, they couldn't litter the entire trail with sensors. And the Vietnamese figured out how to game the system with bags of urine and tape-recorded truck sounds.

It might be tempting to dismiss this as another preposterous blunder in a war full of them. But that would be missing a crucial point. The lesson is not that Igloo White's data-gathering technology was limited—though it was—but that the people using the data did not comprehend its limitations. In the 1996 book *The Closed World*, historian Paul N. Edwards describes Igloo White as an example of technological hubris. Military planners thought computers and real-time communications would let them create a "dome of global technological oversight," yielding ever greater certainty about what was happening in the world. But many things don't neatly fit under the dome; life is messy, and not everything can be abstracted into data for computers to act upon.

Data looks different these days, but our faith in the value of it—and the impulse to create an information panopticon—stubbornly remain. Google says it wants to "organize the world's information and make it universally accessible and useful." Morozov is right to question whether that is a worthy aim. Who knows what data analysis projects being carried out now will look as blinkered in 40 years as Igloo White does today?

Brian Bergstein is deputy editor of MIT Technology Review.

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MIT Technology Review

Demo

Nanotube Computers

IBM creates a new way to make faster and smaller transistors

By David Talbot
Photographs by Andrew Sullivan


Supratik Guha

Researchers at IBM have assembled 10,000 carbon nanotube transistors on a silicon chip. With silicon transistors approaching fundamental limits to continued miniaturization, the IBM work points toward a possible new way of continuing to produce smaller, faster, more efficient computers.

Earlier work by IBM showed that nanotube transistors could run chips three times faster than silicon transistors while using only a third as much power. And at just two nanometers in diameter, the nanotubes—carbon molecules resembling rolled-up chicken wire—are so small that chip makers could theoretically cram far more transistors on a chip than is possible with silicon technology. But controlling the nanotubes' placement in arrays numerous enough to be useful—ultimately, billions of transistors—is a major research challenge.

At IBM's T.J. Watson Research Center in Yorktown Heights, New York, researchers are etching tiny trenches on silicon


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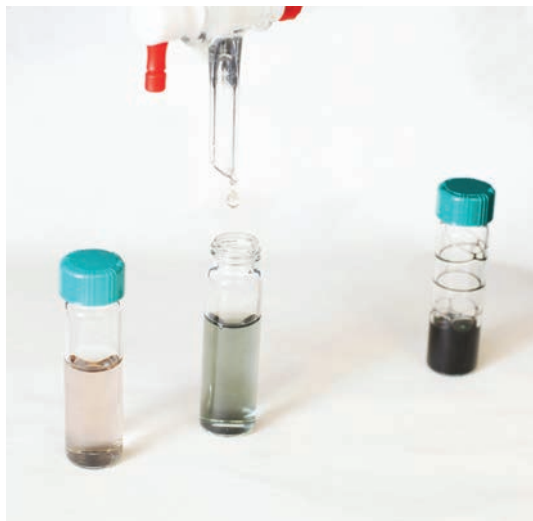

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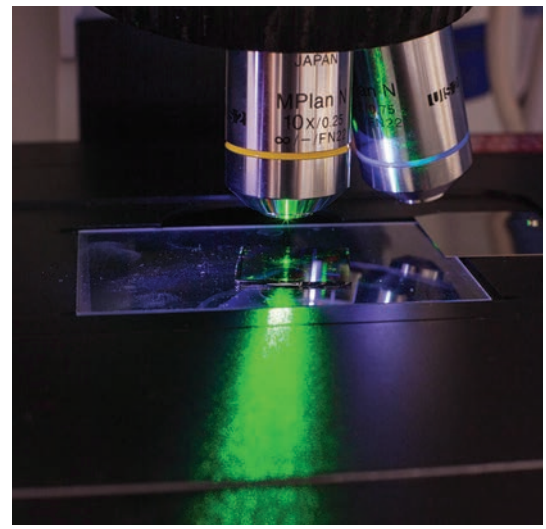

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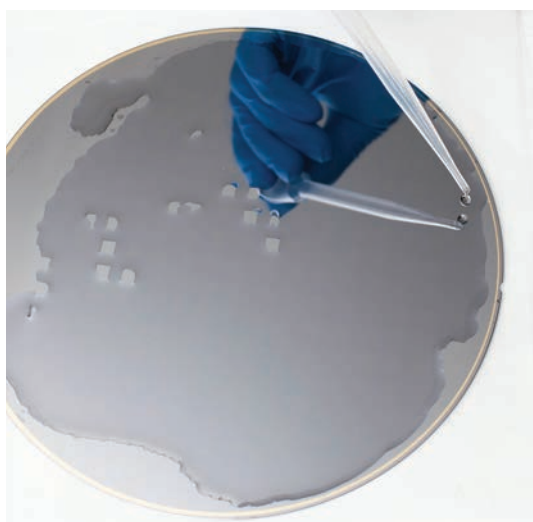

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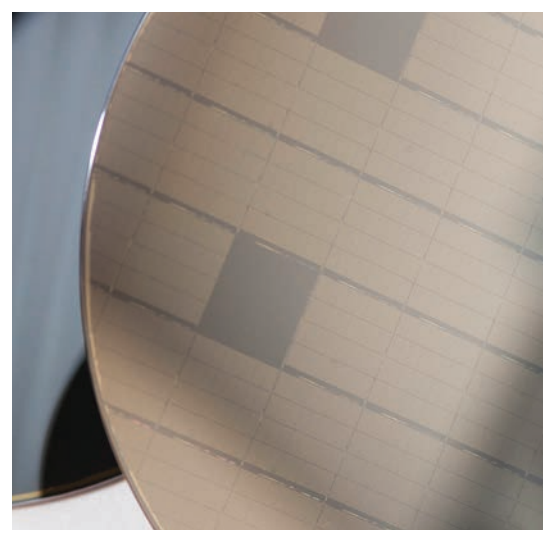


05

01 A sooty powder is obtained by burning a carbon source with an electric arc. About one-fourth of the material consists of carbon nanotubes, tube-shaped molecules of carbon atoms. These are extracted by processing the powder with liquid surfactants in a centrifuge.

02 Passing raw nanotubes (black vial) through a gel separates desirable semiconducting ones (light pink vial, left) from undesirable metallic ones (middle vial); the metallic ones pass through faster.

03 Green laser light illuminates a sample of semiconducting nanotubes in a technique called Raman spectroscopy, a means of determining sample purity. The goal: batches in which fewer than one nanotube in a million is metallic.

04 A conventional 200-millimeter silicon wafer, etched with 100-nanometer trenches 150 nanometers apart (not visible), gets two liquid baths. First a molecular glue binds to the bottom of the trenches; then semiconducting nanotubes bind to the glue, forcing them to line up in the trenches.

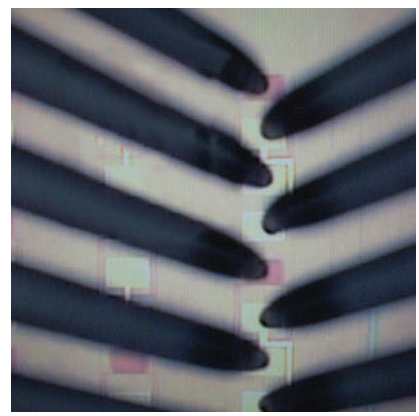
05 The resulting wafer contains 40 chips, each with at least 10,000 nanotube transistors. The visible patterns are metal test contacts, added later by conventional lithography.

06 Shu-jen Han, an IBM researcher, places the finished wafer in a probe station for testing.

07 A magnified view shows black electrical probes touching metal test pads (pink and white squares) on the chip to measure voltages across the nanotube transistors (not visible). The 0.1-millimeter test pads are wired to the far smaller transistors.

08 In this micrograph, five metal pads cover four trenches containing barely visible thread-like nanotubes. For purposes of testing, the entire underlying wafer serves as one gate that switches all the nanotube transistors on or off when a voltage is applied. The IBM researchers are working out ways to add molecular posts to serve as gates for individual transistors.

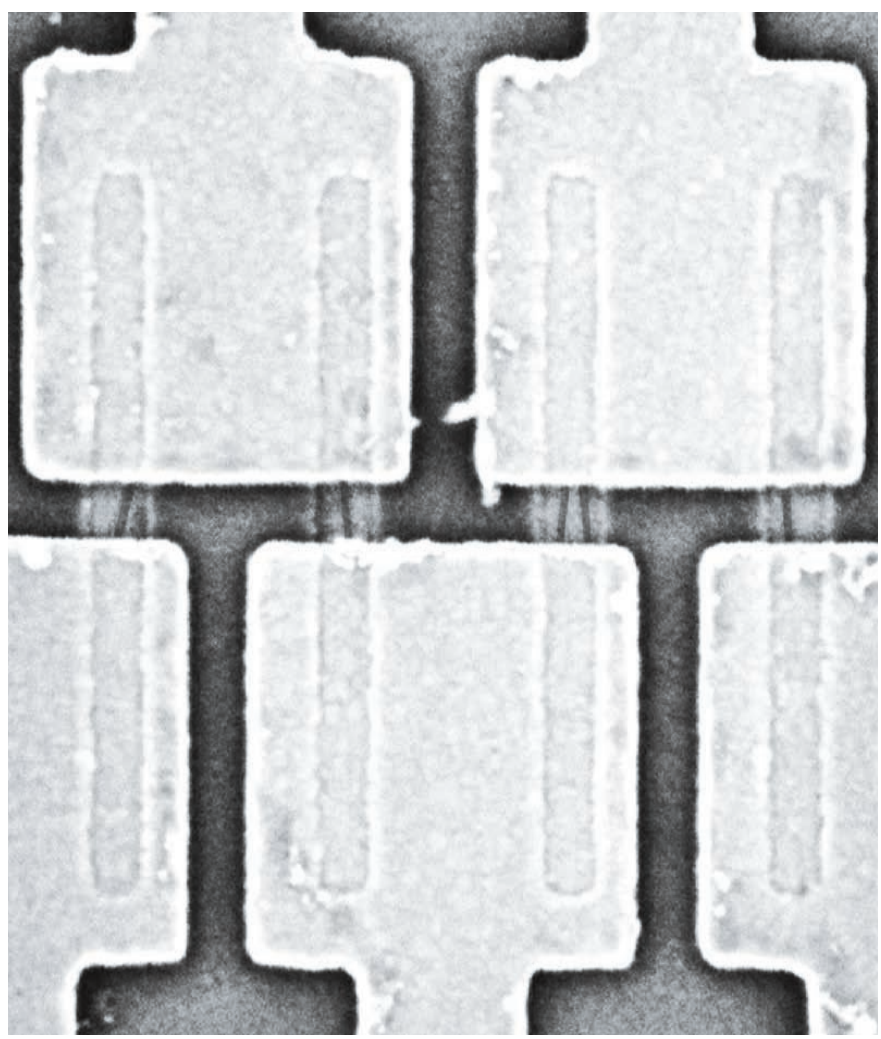
06



07

and using a multistep process to precisely align semiconducting nanotubes in them. Then they add metal contacts to test the nanotubes' performance. The company hopes that by using a silicon substrate, the process can eventually be inserted as a few extra steps within existing fabrication plants.

In the samples the researchers have created so far, the nanotube transistors are about 150 nanometers apart. They'll have to get closer if the new technology is to beat today's silicon transistors and keep ahead of improved generations over the next decade. "We need to lay down a single layer of carbon nanotubes spaced a few nanometers apart," says Supratik Guha, director of physical sciences at the lab. His group must also work out how to add individual electrical contacts, envisioned as atomic-scale vertical posts, to each of billions of transistors; right now the wafer acts as the gate switching the nanotubes on and off. And finally, they must find ways to generate ultrapure supplies of semiconducting carbon nanotubes so that few, if any, will fail or short out. While achieving all this is likely to take five to 10 years, Guha says, "nanotubes are an excellent candidate to keep the scaling of microelectronics technology going."



08

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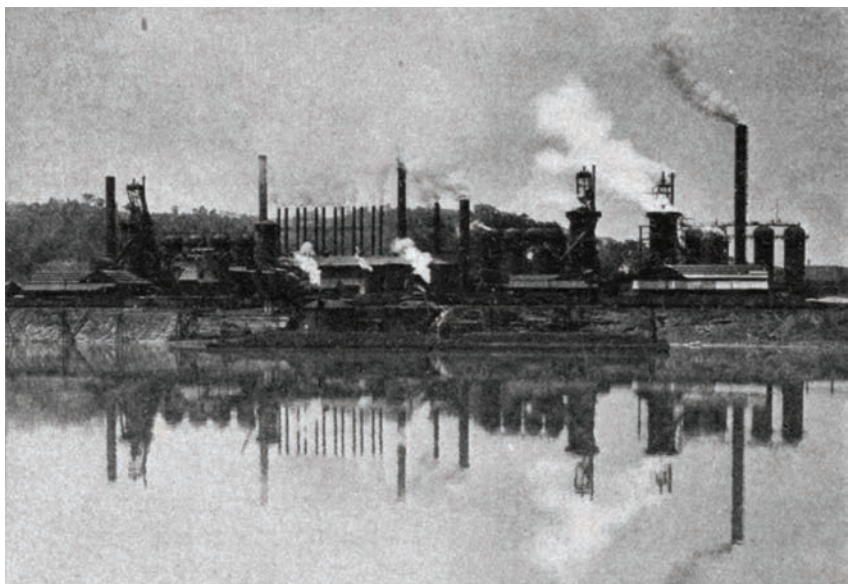

A steel plant on the Allegheny River in Pennsylvania.

Automation Sets Us Free

A 1929 essay by Arthur D. Little argued that workers and consumers would benefit from more mass production, not less.

We are living in the age of science, the machine, and mass production. Like all the ages which have gone before, it is not without its contemporary critics. They would have us believe that … the worker has become the slave of the machine, and that mass production has engulfed us in materialism, converted the craftsman into the tightener of the bolt, and robbed the world of beauty … All this, if true, would be, indeed, a sorry outcome of the long series of intellectual triumphs which, during the last one hundred and fifty years, have given man so large a measure of mastery over his environment …

What, then, is the actual relation of the worker to the machine, and what is the relation of the machine itself to society at large? … For many years manual workers entertained the fallacy that there is only so much work to be done in the world. Since its amount seemed to them hardly sufficient to keep them all employed, it appeared obvious that any device that enabled one man to do the work of two must deprive the second man of his job.

The typewriter undoubtedly displaced some copying clerks, but it provided employment for a far greater number of typists … and provided jobs for thousands in factories for manufacturing the machines and their accessories … The introduction of pneumatic tools like the riveter, drill, and stone chisel undoubtedly, for a time, deprived some men of work, but they so facilitated metal and stone work, the sinking of foundations, and the fabrication of steel structures …

The many excellent persons who anticipate with horror the ultimate standardization of the world through mass production should realize that the field of mass production is very definitely limited and its extension subject to check by many factors. Powerful among them are the demands of style, the desire for individual expression in clothes and surroundings, and the purchases resulting from what Veblen calls 'pecuniary emulation,' which, in the American vernacular, means 'keeping up with the Joneses' …

Mass production is here to stay, however, and the charge that it is incompatible with beauty cannot be lightly dismissed … But even in a machine age there is still hope for the creative arts. The machine is saving us much time. We produce, transport, and distribute the necessities of life with the expenditure of a small fraction of the time and effort required of our forefathers. The time cost of living has gone down. The machine is creating leisure, and we now need schools to instruct us in its use."

Excerpted from "Research and Labor: A Chemist Looks at Modern Life," in the December 1929 issue of The Technology Review, *by Arthur D. Little, founder of the management consulting firm that bears his name.*

EWING GALLOWAY

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